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Vol. XX, Part IV

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ORIGINAL ARTICLES

CYTOGENETIC STUDIES ON CROSSES OF *GOSSYPIUM ANOMALUM* WITH CULTIVATED COTTONS

II. SUBSTITUTION AND ADDITION OF *ANOMALUM* CHROMOSOMES TO THE GENOME OF CULTIVATED TETRAPLOID COTTONS

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(Received for publication on 14 September 1949)

(With Plates XXVIII—XXX)

In a previous communication [Deodikar, 1949], the author has presented the results of his studies on the meiotic chromosome behaviour in the first backcross generation (AA DD B) derived from [(*G. hirsutum* (AA DD)$\times$*G. anomalum* (BB), F_1 Doubled) $\times$ *G. hirsutum* (AA DD)] crosses. As a result of these studies on the first backcross individuals, it could be inferred that if they are subjected to repeated backcrossing with *hirsutum* parent, one or more of the following results can be expected :

1. Probable exchange of genes between A and D sets of cultivated New World Cottons (AA DD) through the bridging influence of *anomalum* B-genome.
2. Transfer of *anomalum* genes to A or D chromosomes.
3. Substitution of A or D chromosomes by their partial homologues from the *anomalum* B set.
4. Addition of *anomalum* chromosomes to the AA DD complement of cultivated New World Cottons.

Observations on the second backcross populations, raised by further crossing the first backcross individuals to the *hirsutum* parent, both in a direct and reciprocal manner, have revealed that some of these expectations appear to have been actually realized. The present paper summarizes the cytogenetic studies on the second backcross [(*G. hirsutum* $\times$ *G. anomalum*) F_1 Doubled) $\times$ *G. hirsutum*^{2}]. It contains derivatives with some of their *hirsutum* chromosomes substituted or supplemented by *anomalum* chromosomes.

Material

The first backcross individuals were mostly sterile though they showed stray setting at the rate of one or, rarely, two well developed seeds per boll. During

the first year of their growth, the 19 first backcross individuals gave 45 such seeds out of which only ten germinated into seedlings and eight developed to maturity. These eight seedlings which represent the F_2 generation of the first backcross (B_1—F_2) were grown in pots in the glass-house during their earlier period of growth and after the fixation of their root tips were transplanted in the field.

The first backcross individuals [(*hirsutum* × *anomalum*) F_1 Doubled) × *hirsutum*], hereafter denoted as B_1, were further backcrossed to the *hirsutum* parent (Co_2an improved strain of acclimatized *hirsutum* cottons from Coimbatore, South India) reciprocally as given below :

(1) $\dfrac{[(CO_2 \times \textit{anomalum})\ F_1 \text{ Doubled}) \times CO_2]}{B_1 \text{ as seed parent}} \times \dfrac{CO_2}{\text{pollen parent}}$

(2) $\dfrac{CO_2}{\text{Seed parent}} \times \dfrac{[(CO_2 \times \textit{anomalum})\ F_1 \text{ Doubled}) \times CO_2]}{B_1 \text{ as pollen parent}}$

Detailed results of the crosses are given in Table I.

TABLE I

Seed setting in reciprocal backcrosses of B_1 to CO_2

Direction of the cross	Number of flowers crosspollinated	Number of bolls set	Percentage of bolls set	Number of seeds obtained	Mean number of seeds per flower pollinated	Mean number of seeds per boll	Percentage of germination
1. $B_1 \times Co_2$	260	107	41	486	1·9	4·6	5·6
2. $Co_2 \times B_1$	218	52	24	157	0·7	3·0	8·3

Abortive, half developed ovules and empty shrivelled seeds were all discarded and apparently well filled seeds alone were considered as crossed-seeds. It will be seen from Table I that the cross (1) is superior to cross (2) in respect of setting of bolls and seeds whereas cross (2) is superior in respect of the germinating capacity of the seeds. Seeds from both these crosses showed considerable variation in their size, the range of variation being greater in seeds from ($B_1 \times Co_2$) than in($Co_2 \times B_1$). The crossed seeds were sorted on the basis of their size, into seven convenient grades in the case of ($B_1 \times Co_2$) and five grades in the case of ($Co_2 \times B_1$). Details regarding the seeds under each of these grades are given in Table II.

TABLE II

Characters of cross seeds under different grades

Percentage	Grade number of cross seeds	Total number	Total weight in gm.	Mean weight per seed in mg.	Mean length in mm.	Mean maximum breadth in mm.	Number of seeds germinated	Germination per cent	Conditon of cotyledons	Condition of embryo
$B_1 \times Co_2$	I	84	7·10	84·5	9·9	6·3	18	22	Normal	Normal
,,	II	73	4·70	64·0	8·5	5·6	9	12	Normal	Normal
,,	III	130	5·13	39·5	8·1	5·1	*nil*	*nil*	Normal	Normal
,,	IV	61	1·77	29·0	7·5	4·5	*nil*	*nil*	Shrivelled	Normal
,,	V	36	0·98	24·4	7·2	4·7	*nil*	*nil*	Partial degeneration	Shrivelled
,,	VI	63	1·25	19·9	6·6	4·2	*nil*	*nil*	Rudiments	Partial degeneration
,,	VII	39	0·55	14·1	5·8	3·7	*nil*	*nil*	Absent	Rudiments
$Co_2 \times B_1$	I	9	1·21	135·0	10·5	7·0	6	75	Normal	Normal
,,	II	40	3·84	96·0	10·3	6·5	7	18	Normal	Normal
,,	III	45	2·25	50·0	8·7	5·4	*nil*	*nil*	Normal	Shrivelled
,,	IV	40	1·37	34·0	7·5	4·9	*nil*	*nil*	Shrivelled	Partial degeneration
,,	V	23	0·65	28·0	0·9	5·2	*nil*	*nil*	Degenerated or rudiments	Rudiments or absent

The mean length and mean maximum breadth of seeds were determined by averaging the measurements on five seeds from each of the grades. A few seeds (one to three) from each of the grades were cut longitudinally through the micropyle and relative development of embryo and cotyledons examined. It will be seen from Table II, that the mean seed weight is higher with Co_2 as the seed parent. Except in grades I to III, the rest showed progressive degeneration of cotyledons. Embryo was usually present regardless of the cotyledons in all but the lowest grades. However, seeds from only the first two grades showed some germination, the percentage for corresponding grades being higher in the case of ($Co_2 \times B_1$) than in ($B_1 \times Co_2$). The failure of germination in the remaining grades may be due to degeneration of cotyledons and in the lowermost grades, to the imperfectness or total lack of the embryo as well.

The seedlings which represent F_1 generation of the second backcross ($B_2 \times F_1$) were allowed to grow in pots during the earlier period of growth and after the collection of their root tips were transplanted in the field. Of the 27 seedlings from ($B_1 \times Co_2$) Cross, 4 died subsequently and 23 developed to maturity. Similarly, out of 13 seedlings from ($Co_2 \times B_1$) cross, only nine developed to maturity. The seedlings showed considerable variation in their vegetative growth and vigour, the range of variation being wider when B_1 was the seed parent. At the time of transplanting (about 7 weeks after germination), the mean heights

of the plants from the backcrosses ($Co_2 \times B_1$) F_1 and ($B_1 \times Co_2$) F_1 were, $49{\cdot}0 \pm 2{\cdot}4$ cm. (range 40 cm. to 61 cm. and $33{\cdot}5 \pm 3{\cdot}4$ cm. (range 9 cm. to 68 cm.) respectively. The difference of 15·5 cm. between the two means, is very highly significant (significant difference at one per cent level is 11·4). These differential variabilities in growth, vigour and morphological characters of these two populations persisted even during subsequent developement to maturity. The ($B_1 \times Co_2$) F_1 plants also showed greater variability in height, growth habit, internode length, leaf size, shape and hairiness and in morphological characters of flowers, bolls, seeds and fibres. They showed predominance of the wild characters of the *anomalum* parent to a varying degree. In contrast, the ($Co_2 \times B_1$) F_1 plants showed only a small range of variation in respect of the corresponding morphological traits and exhibited only traces of the wild *anomalum* characters which in some cases were difficult to recognize with certainty.

As regards the range of variability of these two second backcross populations in respect of sterility, yield, seed setting and other characters of economic value the observations have been summarized in Table III.

TABLE III

Relative fertility and variation in economic characters in ($B_1 \times Co_2$) F_1 and ($Co_2 \times B_1$) F_1

Serial number	Observations	$B_1 \times Co_2$	$Co_2 \times B_1$
1	Total number of B_1 plants raised to maturity	23	9
2	Number of completely sterile plants which did not set any seed	12	0
3	Number of partially fertile plants which showed variable seed setting	11	9
4	Range of variation in yield of seed cotton per plant	0·21 gm. to 35·0 gm.	11·7 gm. to 122·5 gm.
5	Mean yield of seed cotton per plant (partially fertile)	$9{\cdot}57 \pm 3{\cdot}31$	$65{\cdot}43 \pm 10{\cdot}50$
6	Range of variation in the total number of seeds per plant	3 to 208	29 to 420
7	Mean number of seeds per plant (partially fertile)	$44{\cdot}0 \pm 23{\cdot}2$	$194{\cdot}9 \pm 39{\cdot}2$
8	Range of variation in the ginning percentage	30·0 per cent to 45·4 per cent	39·7 per cent to 46·8 per cent
9	Mean value for ginning percentage	$39{\cdot}96 \pm 1{\cdot}26$	$41{\cdot}88 \pm 0{\cdot}74$
10	Range of variation in staple length (Butterfly method)	19·7 mm. to 28·5 mm.	21·3 mm. to 26·0 mm.
11	Mean staple length	$22{\cdot}54 \pm 1{\cdot}04$	$23{\cdot}53 \pm 0{\cdot}45$

Plate XXVIII

Camera lucida drawings

Somatic chromosomes : (1) 2n =53 ; (2) 2n=54 ; (3) 2n=55.

Meiotic chromosomes : (4) late diakinesis, 2 I + 25 II + 1 III (2n=55), distorted pairing at 6 o'clock ; (5) first m-phase, 23 II + 3 III (2n=55) ; (6) first m-phase 2 I + 25 II + 1 III + 1 fragment (2n=55 + 1 fr.), six bivalents showing precocious separation forming chromotin bridges. (7) Insipient anaphase 3 I + 26 II (2n=55), five chromatin bridges, bivalent with distorted pairing at 6 o'clock ; (8) insipient anaphase, 3 I + 26 II (2n=55) seven chromatin bridges ; (9) late telephase with excluded univalents. (10) one chromatin bridge at late telophase (11) four chromatin bridges at late telophase (12) a chromatin bridge a fragment and 3 univalents showing longitudinal split at l ate telophase.

Magnification circa 1500.

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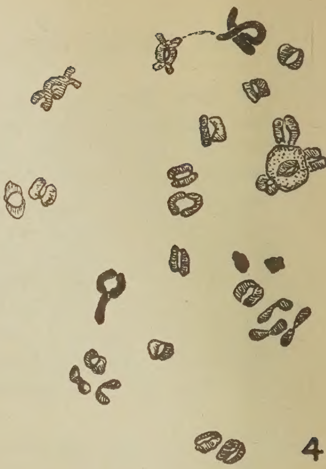

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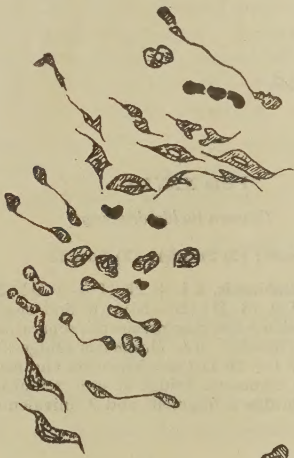

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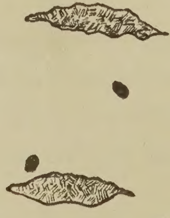

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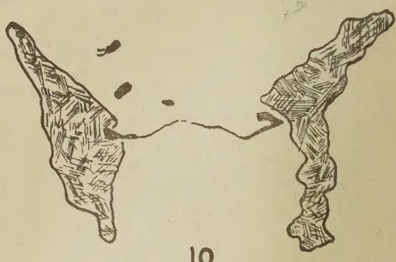

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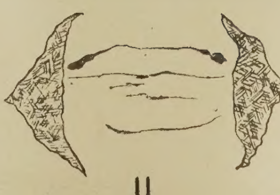

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12

In the case of Co_2, the recurrent *hirsutum* parent, the corresponding values for economic characters during the same season were as follows : Mean yield per plant 66·5 grams (on a separate plot and therefore, under conditions not strictly comparable with the above) ; ginning outturn 37·5 per cent ; staple length 23·7 mm.

Owing to the extremely poor germination of the crossed seeds, very few B_2 plants were available for study. However, it will be seen from the data given in Table III that the two crosses, though reciprocals involving the same two parents, are very distinct from each other in respect of three out of the four characters studied, *viz.* (i) mean yield of seed cotton per plant, (ii) mean number of seeds per plant, and, (iii) mean ginning percentage. It need hardly be stated that they are significantly different in these characters. It is only in staple length that they are not dissimilar to one another.

In respect of all the four characters referred above ($B_1 \times Co_2$) show much wider range of variation than ($Co_2 \times B_1$). However, this wider range of variation in economic characters in the former case, does not provide correspondingly greater scope for selection due to their relatively high degree of sterility.

Cytological procedure

Root tips were pretreated in Carnoy's fluid for a few seconds and then transferred to Craff's A and B in equal volumes containing a trace of maltose. After 24 hours in the fixative the root tips were subjected to washing, dehydration, infiltration and paraffin embedding in the usual manner. They were sectioned at 12 microns and stained by gentian violet—iodine—dichromate method.

Flower buds were collected during December to February (1947-48) between 11 a.m. to 12 noon on bright sunny days, and fixed in Carnoy's from four to six hours, treated in an equal mixture of concentrated HCl and 95 per cent alcohol for five minutes at 45C., repeatedly rinsed in 95 per cent alcohol and temporarily stored in alcohol of the same strength. Anthers at proper stages were smeared in aceto-carmine containing a trace of ferric chloride. Slides were sealed with paraffin and these temporary mounts were used for microscopic examination.

All chromosome drawings (Plate XXVIII, figs. 1 to 12) were made at bench level with the aid of a camera lucida using 1·8 achromatic oil immersion objective (95x) and compensating occular (15 X). All photomicrographs (Plate XXIX, figs. 1 to 6 and Plate XXX, fig.1) were taken at Circa 750 × and subsequently magnified two times.

Somatic chromosome numbers

Somatic chromosome numbers were determined in the case of individual plants of (B_1 F_2) referred to earlier, as also of the second backcrosses ($B_1 \times Co_2$) F_1 and ($Co_2 \times B_1$) F_1. The observations have been summarized in Table IV.

TABLE IV

Somatic chromosome numbers in (B_1 F_2) and (B_2 F_1) populations
[*Chromosome numbers* (*2n*)]

Population	53	54	55	56	57	58	59	60	61	62	65	66	68	69	70	71	75	Total
B_1 F_2	1	..	..	2	..	1	..	1	1	1	..	..	..	..	..	1	..	8
(B_1 × Co_2)	..	..	..	3	3	2	2	1	1	2	2	1	3	1	1	..	1	23
(Co_2 × B_1)	1	3	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9

It will be seen from Table IV that (B_1 F_2) showed very wide range in chromosome numbers of its individual plants from 2n = 53 to 71. When the first backcross individuals (B_1) were used as seed parent and Co_2 as pollen parent, the resulting second backcross population, (B_2 F_1), also showed wide range of chromosome numbers from 2n = 56 to 75. However, it is very interesting to note that in the case of the reciprocal cross with B_1 by as pollen parent, the resulting second backcross population showed extremely small range of variation in chromosome numbers of individual plants from 2n = 53 to 55. Differences in the two second backcross populations as regards the range of variability in morphological and economic characters are very probably the result of corresponding differences in the range of variability of chromosome numbers of their individual plants.

The recurrent *hirsutum* parent Co_2 (2n = 52) gave relatively uniform gametes with 26 chromosomes. The first backcross individuals (2n = 65+ 0 to 4) have an allopentaploid constitution (AA DD B) and their gametic chromosome numbers are highly variable due to irregular meiotic behaviour of univalents and non-disjunction and unequal anaphasic separation of multivalents, leading to the formation of some normal tetrads as also monads, diads and a large number of micronuclei, at the end of meiosis [Deodikar, 1949]. It was observed that a micronucleus may develop even from a single isolated univalent and the diads or monads rarely present at the end of meiosis might contain the full set of chromosomes (2n = 65 + 0 to 4). If we take into account such extreme cases, gametic chromosome number in the B_1 individuals may vary over a very wide range from 1 to 65 + 0 to 4. As shown in Table IV, the B_2 plants raised from (B_1 × Co_2) cross had their chromosome numbers ranging from 56 to 75. If we deduct 26 chromosomes contributed by Co_2, the pollen parent, it would appear that female gametes of B_1 plants containing 30 to 49 chromosomes were functional and the rest were either not formed at all or were eliminated as a result of gametic or zygotic inviability (Table III). In the case of reciprocal cross, however, male gametes of B_1 individuals containing 26 to 29 chromosomes alone may be said to have been compatible with the 26 chromosome female gametes of Co_2 and the rest of the B_1 male gametes with lower and higher chromosome numbers were either non-functional or unsuccessful in competition with the former. Thus, the 26 chromosome female gametes of Co_2

seem to have had preferential affinity for only those male gametes from B_1 individuals which contained 26 + 1 to 3 chromosomes. This accounts for the strong contrast between ($B_1 \times Co_2$) F_1 and ($Co_2 \times B_1$) F_1 populations in respect of their chromosomal and morphological variability and fertility (Table III). Evidently, the latter should be expected to provide far greater scope for selecting types of economic utility. Comparative study of these two second backcross populations also indicated that ($Co_2 \times B_1$) F_1 individuals were likely to provide a surer and quicker way of securing types with the desired combinations of economic characters of immediate practical value either as such or as a material for further breeding programme. These considerations stimulated particular interest in the study of meiotic chromosome behaviour in the ($Co_2 \times B_1$) F_1 individuals.

Meiosis in ($Co_2 \times B_1$) F_1 plants

Since the chromosome numbers in B_2 plants derived from ($Co_2 \times B_1$) cross occur as $2n = 52 + 1$ to 3, it was tentatively inferred that the extra 1 to 3 chromosomes over the normal number ($2n = 52$) of the recurrent parent, possibly consisted of the added *anomalum* chromosomes. The general course of meiosis observed in the first backcross individuals was such that it would invariably lead to the formation of some gametes wherein a few of the chromosomes in the normal (AA DD) complement of the recurrent *hirsutum* parent would be substituted by their corresponding partial homologues from the *anomalum* B set [Deodikar, 1949]. Therefore, ($Co_2 \times B_1$) F_1 plants may be expected to contain a variable number of *anomalum* chromosomes each of which may exist either as substituted in the place of its partial homologue within the (AA DD) complement or as added to the (AA DD) complement of the recurrent *hirsutum* parent. Critical study of meiosis in these B_2 plants revealed certain characteristic features which could be used as criteria for identifying such added and substituted *anomalum* chromosomes. Certain essential observations on meiotic chromosome behaviour, which are relevant for this purpose, may be outlined here in brief.

(i) *Presence of 26 bivalents with occasionals light variations.* (Plate XXVIII, figs. 7 and 8) this implies that in the case of the ($Co_2 \times B_1$) cross, when 26 chromosome (AD) eggs of Co_2 show preferential fusion with B_1 male gametes with 26 + 1 to 3 chromosomes, these latter are so constituted that 26 of their chromosomes collectively make up the full (AD) complement of *hirsutum* parent, either as such or with a few substituted *anomalum* homologues. Therefore, female gametes of Co_2 show preferential fusion only with such B_1 male gametes which are genomically well-balanced and complete (AD), apart from extra 1 to 3 added *anomalum* chromosomes which they may contain.

(ii) *Presence of 1 to 3 univalents.* The univalents showed themselves conspicuously during meiosis by their differential behaviour from rest of the paired chromosomes. They had marginal or isolated orientation on the meta-phase plate, were usually static during anaphase, lagged behind during telophase and were sometimes eliminated from rest of the chromosomes during interkinesis (Plate XXVIII,

figs. 4 to 9 ; Plate XXIX, figs. 1 to 4). The maximum number of such univalents observed during meiosis in each of the B_2 individuals was equal to the number of chromosomes in excess of 52 as recorded from the somatic counts (Table V). This supports the presumption that these extra chromosomes represent in all probability the added *anomalum* univalents.

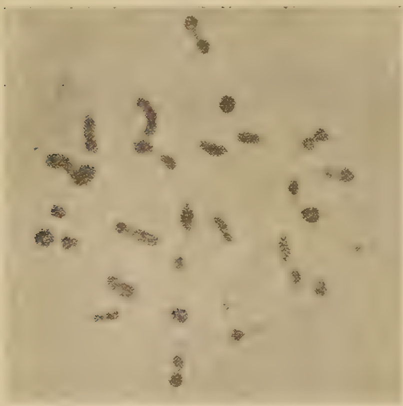
(iii) *Rare occurrence of 1 to 3 trivalents.* (Plate XXVIII, figs. 4 to 6 ; Plate XXIX, figs. 5 to 6). Occurrence of a certain number of trivalents in a particular P. M. C. resulted in corresponding reduction in the maximum number of univalents and bivalents as recorded in other P. M. C. S. of the same plant as shown below :

2n	*Meiotic conjugations*
52 + 1 . .	(1) 26 II + 1 I, (2) 25 II + 1 III
52 + 2 . .	(2) 26 II + 2 I ; (2) 25 II + 1 III + 1 I ; (3) 24 II + 2 III
52 + 3 . .	(1) 26 II + 3 I ; (2) 25 II + 2 I + 1 III ; (3) 24 II + 1 I + 2 III ; (4) 23 II + 3 III

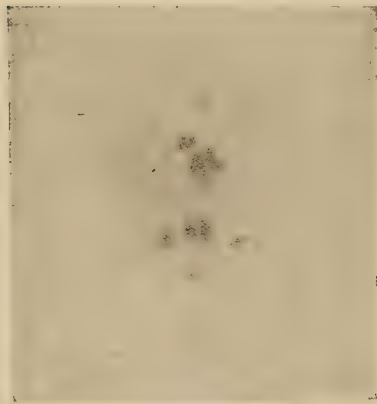
This implies that 1 to 3 extra *anomalum* chromosomes which ordinarily appeared as univalents, may rarely enter into trivalent associations with such of the pairs of *hirsutum* chromosomes with which they are partially homologous. The maximum number of univalents or trivalents observed in any of the B_2 individuals may, therefore, indicate the probable number of added *anomalum* chromosomes.

(iv) *Loose bivalent associations at prophase.* Associations of terminal or sub-terminal segments of one chromosome with median or sub-median regions of another leading to loop formation or distorted pairing, were frequently observed (Plate XXVIII, figs. 4 and 7). This possibly indicated the pairing of substituted *anomalum* chromosomes with their partial homologues from the *hirsutum* complement. In the absence of their identical homologues, the two chromosomes have to enter into such obligatory associations. Loose distorted pairing of this type might be due to different linear sequence of homologous genes caused by inversions, translocations, duplications, deletions and such other changes that differentiate the originally homologous chromosomes in the course of evolution of related species.

(v) *Presence of chromatin bridges during ana-and telophases.* (Plate XXVIII, figs. 10 to 12 ; Plate XXX, figs. 8 to 10). The presence of such bridges furnished a definite proof for the presence of pairing between chromosomes with inversions. The number of bridges observed can, therefore, be used as an indirect criterion to ascertain the number of substituted *anomalum* chromosomes. However, all such substituted chromosomes may not necessarily involve inversions and there may not be crossing over in the inversion region whenever such chromosomes may pair, so that some inversions may not express themselves through bridge formation. The maximum number of bridges per P. M. C. observed in an individual plant, therefore, may represent only the minimum number of substitute *anomalum* chromosomes, many of which may escape detection through such visual criteria.

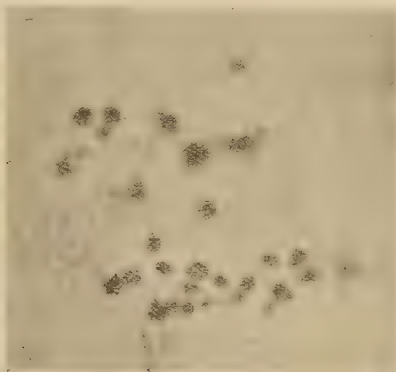


(1) first m. phase showing 2 I+25II+1 III+1 fragment at 6 o'clock (2n=55)



(2) Bivalents at late diakinesis with a univalent at 5 o'clock

(3) Univalent outside the m—phase plate



(4) Univalents lagging at first anaphase

(5) Two trivalents at insipient anaphase I

(6) a trivalent at insipient anaphase II

(7) 2—1 separation of trivalent at anaphase I ;

(8) a trivalent lagging at telophase I ;

(9) chromatin bridges at telophase and anaphase I ;

(10) chromatin bridges at telophase and anaphase I.

PLATES XXIX AND XXX

Photomicrographs.

(1) first m. phase showing 2 I+25 II+1 III+1 fragment at 6 o'clock (2n=55) ; (2) Bivalents at late diakinesis with a univalent at 5 o'clock ; (3) Univalent outside the m—phase plate ; (4) Univalents lagging at first anaphase ; (5) Two trivalents at insipient anaphase I ; (6) a trivalent at insipient anaphase I ; (7) 2—1 separation of a trivalent at anaphase I ; (8) a trivalent lagging at telophase I; (9) and (10) chromatin bridges at telophase and anaphase I.

Magnification *circa* 1,500×, except (8) and (9) where it is circa 750×.

The maximum number of univalents, trivalents and bridges observed during meiosis in each of the B_2 individuals, therefore, was taken as a basis for estimating roughly the number of added and substituted *anomalum* chromosomes, subject to certain limitations as explained above. Tentative inferences as regards the probable number of added and substituted *anomalum* chromosomes present in individual plants from the second backcross population have been summarized in Table V.

TABLE V

Probable number of added and substituted anomalum *chromosomes in B_2 plants derived from the (Co_2 × B_1) cross*

Serial number	Pot-culture number	Chromosome number	Maximum number per pollen mother cell (P. M. C.)			Probable number of *anomalum* chromosomes	
			Univalents	Trivalents	Bridges	Added	Substituted
1	8/1	52+1	1	1	1	1	1
2	8/2	52+2	2	2	3	2	3
3	8/3	52+2+1 fragment	2	..	2	2+1 fragment	2
4	8/9	52+2+1 fragment	2	..	2	2+1 fragment	2
5	8/5	52+3	3 (very rarely 5)	..	3		3
6	8/6	52+3	3	..	..	3	..
7	8/7	52+3	3	3	1	3	1
8	8/8	52+3	3	..	7	3	7
9	8/10	52+3	3	..	2	3	2

Pot-culture 8/5 normally showed three univalents which corresponded to the number of extra chromosomes (52+3) it contained. On very rare occasions, however, it showed five univalents which may have been due to the failure of one of its substituted chromosomes to pair with the corresponding partial homologue from the *hirsutum* complement. Trivalents were observed only in three out of the nine B_2 individuals. This indicates that the added *anomalum* chromosomes do not always associate with their partial homologues in the *hirsutum* (AA DD) set. Pot-culture 8/8 showed as many as seven anaphasic bridges per P. M. C. so that it probably contained at least seven substituted *anomalum* chromosomes which is the maximum number observed among all the B_2 individuals. This is corroborated by the fact

that among all the B_2 individuals, pot-culture (8/8) is the least fertile (or relatively more sterile), morphologically distinct, and shows more conspicuosly the presence of many characters from the wild *anomalum* parent.

General considerations

In the two second backcross populations studied here, the number of individual plants that could be secured was too small. In view of the superior performance of $(Co_2 \times B_1)$ F_1 population, additional crosses of this type are to be attempted on a large scale so as to raise a B_2 population of sufficient size which may contain individuals with desired combinations. Inspite of the small size of the B_2 populations studied here, observations that have been presented have some utility as indicative of certain trends. These general trends may be discussed here in short.

(i) *Differential performance in reciprocal crosses.* Female and male gametes of B_1 individuals differ significantly in their capacity to transmit chromosomal abnormalities. Similar observations have been recorded in many other unbalanced polyploids. Thus, Clausen and Goodspeed [1926] observed that in monosomics and trisomics of *Nicotiana*, ovules show higher transmission of chromosomally unbalanced forms as compared to pollen grains which are eliminated in competition with those containing the normal number or a full complement. In reciprocal $(2n \times 3n)$ maize crosses, McClintock [1929] noted that when 3n was used as the seed parent, more extra chromosomes were transmitted to the progeny than when the triploid was used as the pollen parent. Punyasing [1947] recorded similar observations on very large populations of reciprocal crosses among 2n, 3n and 4n maize. It would, thus, appear that female gametes show greater disposition for transmitting chromosomal abnormalities as compared to male gametes of the same individual. In such cases, therefore, use of a type with lower chromosome number as a seed parent serves to regulate and reduce the wide range of chromosomal variability so as to render it more useful for certain purposes. Thus, for instance, the use of a type with lower chromosome number as a seed parent in such crosses would provide rapid and reliable means for the artificial synthesis of a series of monosomics and trisomics so as to study individual chromosomes in the haploid set for linkage relationships or for the transference of only one or two desired chromosomes from one species to another. On the contrary, when the type with higher chromosome number is used as a seed parent, the wide range of chromosomal and morphological variability obtained in its progeny may also prove to be of practical utility in the case of plants cultivated through vegetative propagation where sterility and seed setting is immaterial.

(ii) *Mutual compatibility of genomically balanced gametes.* The fact that $(Co_2 \times B_1)$ F_1 individuals with $2n=52+1$ to 3 chromosomes show regular 26 bivalents during meiosis indicates that, inspite of the wide range of variability of gametic chromosome numbers in B_1 individuals, only the gametes containing full (AD) complement are compatible with the AD gametes of Co_2. This is an important factor which ensures the possibility of isolating genomically balanced (AA DD) individuals in the progeny of such unbalanced polyploids producing highly variable

gametes. Thus, even though individual plants from B_1 F_1, B_1 F_2 and B_2 population raised from ($B_1 \times Co_2$) cross, are all mostly sterile and chromosomally variable, we cannot preclude the possibility of isolating from their progenies in subsequent generations, genomically well balanced types with normal fertility. In fact, preliminary observations on F_3 of first backcross (B_1 F_3) and F_2 of second backcross (B_2 F_2) indicate definite improvement over their preceding generations as regards growth, vigour, fertility and general normality and possibly this may be due to progressive restoration of chromosomal balance in successive generations as a result of selective fusion of genomically balanced gametes.

Iyengar [1945] recorded similar observations on the progenies of crosses among [(American $\times$Asiatic)$\times$American] cottons. He observed that individuals with 52 chromosomes originate in such a cross through the fusion of balanced (AD) gametes and even the aneuploids appearing in the same crosses were all nearly balanced genomically, except for the presence or absence of one or two chromosomes. On the basis of his observations on the progenies of autotetraploid maize, Kadam [1944] inferred that mostly the balanced euploid gametes with 20 chromosomes are functional and that hypo-and hyper ploid gametes are eliminated in competition.

(iii) *Substituted* anomalum *chromosomes*. It would appear from Table V that ($Co_2 \times B_1$)F_1 individuals may contain as many as seven substituted chromosomes. It remains to be seen how far these substituted chromosomes can be permanently retained. In view of their genic differentiation, a substituted chromosome is not genetically identical with its partial homologue from *hirsutum* complement. The former cannot, therefore, be incorporated into the genomic constitution of the recurrent parent without disturbing its specific balance. This sometimes leads to gametic or zygotic elimination of the substituted chromosomes. However, there are cases indicating the possibility of either retention or elimination of the substituted chromosomes. East [1927] obtained stable derivatives of *Nicotiana rustica* by replacing a few of its chromosomes by the respective *paniculata* homologues. But reciprocal replacement of *paniculata* chromosomes by *rustica* homologues was not possible since no constant true breeding type could thus be obtained. In the case of *N. tabacum* derivatives with some of the chromosomes substituted by *sylvestris* homologues, the latter get eliminated in successive generations and *tabacum* univalents get doubled through selfing [Clausen and Goodspeed, 1926]. Thus, it is quite possible that the substituted *anomalum* chromosomes may be either retained or eliminated. In the latter case, however, in view of their pairing with the partial *hirsutum* homologues during the meiosis *preceding* their gametic or zygotic elimination, there will be some transfer of anomalum genes to *hirsutum* chromosomes to the extent of the possiblities of crossing-over among such pairs. Therefore, even if substituted chromosomes are eliminated, it should still be possible to transfer some of the desirable *anomalum* characters to the recurrent *hirsutum* parent. For this purpose, the pot-culture 8/8 is important since it may be containing as many as seven substituted chromosomes thereby providing correspondingly greater scope for the transference of desired *anomalum* characters to the recurrent parent.

There have been some instances of substituted chromosomes having been utilised for practical purposes. Holmes [1938] derived a mosaic resistant strain of *N.*

abacum by substituting the 'H' chromosome with its homologue from *N. glutinosa* which carries the resistance genes. Kattermann [1938] succeeded in obtaining strains of wheat containing 20 pairs of normal wheat chromosomes and one pair of rye chromosome. Nishiyama [1939] replaced a pair of chromosome from *Avena fatua* by a pair from *A. barbata*. Such derivatives have been described as 'Alien substituted races' by Clausen to distinguish from 'Alien addition races' which contain new chromosomes added in homologous pairs.

It may be possible to predict roughly the possible mode of segregation of the substituted *anomalum* chromosomes in B_2 F_2 generation. If A is one of the substituted chromosomes in a B_2 F_1 individual pairing with its partial homologue H from the *hirsutum* complement, then B_2 F_2 population should consist of individual of the type $AA : AH : HH$ in the proportion of 1 : 2 : 1 and B_3 F_1 should consist of AH : HH plants as 1 : 1, provided there is random fusion of gametes, due allowance being made for the minor qualitative changes in the chromosomal contents as a result of crossing over. This basic pattern of segregation may be considerably modified if gametic fusion is subjected to selective preferences or if there is gametic and zygotic inviability. In the case of an individual like pot-culture 8/8 with possibly as many as seven substituted chromosomes, the probable number of zygotic combinations would indeed be very large.

(iv) *Added* anomalum *chromosomes*. All B_2 F_1 individuals contain added *anomalum* univalents as single chromosomes. They would give, in about an equal proportion, two types of gametes, differing in respect of the presence or absence of a particular added univalent. If A denotes a gamete with added *anomalum* univalent and O denotes a gamete wherein the added univalent is absent, then B_2 F_2 population should consist of $AA : AO : OO$ types in the ratio of 1 : 2 : 1 and B_3 F_1 should consist of $AO : OO$ in the proportion of 1 : 1, assuming the random fusion of gametes. This basic segregation will be modified by the fact that (i) univalents sometimes get eliminated from tetrads when they form their own micronuclei, (ii) univalents split at ana or telophase of the first meiotic division thus duplicating themselves, (iii) added *anomalum* single chromosomes sometimes form trivalent association with their partial homologues from the *hirsutum* set and non-disjunction or unequal anaphasic separation of such trivalents may introduce some complications. Subject to these limitations, therefore, less than about 25 per cent of the B_2 F_2 population should consist of individuals containing a particular *anomalum* chromosome added as a homologous pair. Since such pair originates through the fusion of two identical *anomalum* univalents, it would be completely homozygous for the *anomalum* characters, introduced through it, in respect of which the new synthetic type would breed true in subsequent generations.

Winge [quoted by Gerstel, 1945-a] produced such true breeding 'Alien addition races' in *Erophylla* through interspecific crossing among forms with different chromosome numbers. He frequently came across univalents splitting during meiosis and developing into homologous pairs. O'mara [1940] added single pairs of rye chromosomes to wheat. Gerstel [1945-a] succeeded in adding an entire chromosome

pair from *N. glutinosa* carrying resistance to mosaic virus, to an unaltered complement of *N. tabacum*. The type thus obtained by him is meiotically stable and true breeding. Clayton [1917] similarly evolved cultivated tobacco resistant to a severe bacterial disease ('wild fire' and 'back fire') caused by *Pseudomonas tabaci* and *P. angulata*, by using the wild species *N. longiflora* which carried immunity genes.

As regards the addition of *anomalum* chromosomes in homologous pairs to (AA DD) complement of the *hirsutum* cottons, the resulting type would be more stable if the *anomalum* chromosome pair so added has the least affinity with any of the members from A or D sets. This will minimise the possibility of multivalent formation and thus render the type more stable. However, there are cases wherein the partial affinity of added chromosomes does not interfere with their meiotic regularity. Thus, in the above case of *N. tabacum* derivative, its 'H' chromosome is homologues with the added *glutinosa* pair carrying resistance to mosaic virus and yet they do not enter into multivalent formation. Gerstel [1945-a] found that more than 92 per cent of the P. M. C. S. in this synthetic type show regular 25 bivalents. Iyengar [1942] has observed that *anomalum* chromosomes show allosyndetic pairing with corresponding partial homologues from the A set of Asiatic cottons but, in the presence of both A and B sets in duplicates, each chromosome shows preferential autosyndetic pairing with their own homologue within the respective sets. In view of this, it would appear that any such derivatives of the New World Cottons with added *anomalum* pairs are likely to be fertile irrespective of their partial homology with some of the members of AA DD complement, since such homology is not likely to manifest itself through multivalent formation.

Discussion

Utility of alien substitution and addition races for the improvement of cultivated crops. Interspecific hybridization between wild and cultivated forms should essentially aim at transference of only a few desired genes so that they can be harmoniously incorporated in the genomic framework of the recurrent parent without disturbing much, its specific balance. It has been stated earlier that Gerstel [1945] has succeeded both in substituting and adding of 'H' chromosome of *N. glutinosa* carrying immunity to the mosaic virus to the *rustica* complement. Kostoff [1948] has observed that it is possible to transfer only the virus immunity gene or the segment containing it through ordinary crossing over and that it is not quite necessary to substitute or add the whole 'H' chromosome for the transference of immunity. Whenever possible, it is better to try for such simple gene transference because it involves the introduction of the least effects of the undesirable wild genes and the new synthetic type would be suitable for retransferring the new gene freely to any other cultivated strains by ordinary plant breeding methods. However, such selective gene transference from one species to another is not always possible since it is conditioned by the degree of chromosome pairing in the F_1 hybrid and the occurrence of cross-over in the particular region on the pairing chromosome where the desired gene is located. Further, inspite of pairing, there may be suppression of such cross-over in the segment concerned due to genetic and/or mechanical reasons.

In such cases, when there is pairing but no cross-over, the desired character can be incorporated in the recurrent parent by substitution of the whole chromosome as a homologous pair. If the chromosome carrying the desired genes does not pair at all in the hybrid, the only way to transfer the desired character is by addition of such chromosome as homologous pair.

The discovery of induced polyploidy by colchicine has furnished a surer method of overcoming the sterility characteristic of interspecific hybrids between cultivated and wild forms. But the resulting amphidiploid in such cases contain the entire duplicated genome of the wild parent so that together with a few desired characters it also contains a large number of undesirable traits due to the usual dominance of the wild genes. These considerations have set limitations on the utility of induced polyploidy in practical plant breeding. As against this situation, by planning appropriate crosses, alien substitution or addition races can be synthesised wherein only the particular chromosome carrying certain desired genes, is transferred from the wild to cultivated forms. Such a procedure enables one to avoid most of the wild genes except those located on the transferred chromosome itself. In view of these considerations, it is possible that, for the purpose of improvement of cultivated crops, synthetic derivatives with one or a few transferred chromosomes may prove to be of relatively greater practical value as compared to the ordinary amphidiploids. From the few recent achievements in this new field it would appear that the synthesis of alien substitution and addition races may furnish an important tool for the improvement of cultivated crops and it represents a definite advance in the technique of modern plant breeding.

Possible utility of G. anomalum *for improving the staple length of the cultivated new world cottons.* Cotton workers from Coimbatore and the Punjab in India have already proved the utility of *anomalum* for improving the staple length of the cultivated *arboreum* cottons. But it is not yet known whether *anomalum* can be of similar use for improving the staple length of the cultivated New World Cottons. Reference to Table III will indicate that in the case of both the B_2 populations, the upper limits of their range of variation of both the staple length and ginning percentage are much higher than those of Co_2, the recurrent *hirsutum* parent. Thus as against the 23·7 mm staple length and 37·5 per cent ginning of Co_2, some of the B_2 individuals show 28·5 mm. staple and some others show 46·8 per cent ginning in addition to a certain degree of fineness and strength in their fibre. From these preliminary indications, it can be said tentatively, that apart from its utility as a source of resistance or immunity genes, *G. anomalum* can also be used for improving the staple length, fineness, strength, and some other quality attributes of the *hirsutum* cottons.

Summary

With a view to transfer some of the economically useful characters of *Gossypium anomalum* (BB) to the *G. hirsutum* (AA DD) cottons, a synthetic hexaploid (*hirsutum* × *anomalum*) (F_1 doubled) [$(ADB)_2$] is being repeatedly backcrossed to Co_2, the recurrent *hirsutum* parent. The present paper summarizes the results of

cytogenetic studies on the two second backcross (B_2) populations raised from the reciprocal crosses ($B_1 \times Co_2$) and ($Co_2 \times B_1$).

The cross ($B_1 \times Co_2$) is superior to ($Co_2 \times B_1$) in respect of setting of bolls and seeds but inferior in respect of the mean weight of the cross seeds and their germinating capacity. Cross seeds in the former case showed wider range of variation in respect of individual seed size and weight. In either case the failure of germination was due to imperfect development or progressive degeneration of cotyledons and/or embryo.

In contrast to ($Co_2 \times B_1$) F_1, the ($B_1 \times Co_2$) F_1 showed wider range of variation in respect of height, vigour, fertility, seed setting, ginning outturn, staple length and other morphological characters. Majority of the ($B_1 \times Co_2$) F_1 plants were completely sterile whereas all the ($Co_2 \times B_1$) F_1 plants were more or less fertile.

Somatic chromosome numbers in ($B_1 \times Co_2$) F_1 varied over a wide range from 56 to 75 as compared to a small range from 53 to 55 in the case of ($Co_2 \times B_1$) F_1.

Meiosis in ($Co_2 \times B_1$) F_1 was characterised by the presence of univalents and/or trivalents. The maximum numbers of univalents or trivalents in an individual plant was equal to the number of chromosomes in excess of 52 as observed in their somatic counts (2n=52 plus 1 to 3). These extra 1 to 3 chromosomes represent the added members from the *anomalum* B genome, which remained either as univalents or occasionally formed trivalent associations with their partial homologues from the *hirsutum* complement. Meiosis in ($Co_2 \times B_1$) F_1 plants was also characterized by loose distorted bivalent associations during diplotene and chromatin bridges during ana and telophases. This was attributed to probable pairing of substituted *anomalum* chromosomes with their partial homologues from the *hirsutum* complement. Maximum number of such anaphasic bridges (1 to 7) observed in an individual roughly gave an approximate estimation as to the number of substituted *anomalum* chromosomes.

Differential performance in reciprocal crosses indicate that the female gametes of B_1 individuals show a greater disposition for transmitting the chromosomal abnormalities as compared to the male gametes of the same individual. It also indicates the mutual compatibility of gametes which are genomically balanced or have a near-approach to that condition.

Discovery of induced polyploidy has enabled to overcome the sterility of interspecific hybrids through the synthesis of amphidiploids. However, these amphidiploids contain entire wild genom in duplicate and therefore show predominance of undesirable wild characters which sets a limitation on their utility for practical cultivation. As against this situation ' alien substitution ' and ' alien addition ' races enable to avoid most of the economically undesirable wild characters except those located on the transferred chromosome itself. Therefore, synthesis of such substitution and addition chromosomal races, represent a definite advance in the technique of modern plant breeding.

This preliminary data seems to give tentative indications that, *G. anomalum*, apart from its utility as a source of certain immunity genes, may prove to be useful for improving the staple length and some other qualities of the *hirsutum* cottons.

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FURTHER STUDIES IN THE GENETICS OF LINTLESSNESS IN ASIATIC COTTONS

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HUTCHINSON and Gadkari [1937] working with seven lintless mutants in Asiatic Cottons, pointed out that the lintlessness was due to the action of five independent genes, h_a, h_b, li_a, li_b and li_c, each one of them being individually able to bring about this effect. Two of these viz. h_a and h_b also bring about glabrous plant body as a pleiotropic effect whereas in case of the other three lintless genes viz. li_a, li_b and li_c the plant body is normally hairy. Their investigations were incomplete with regard to the hairy lintless genes ; as such experimental data was further collected to elucidate the details of their action, inter-relations and linkages. During the course of this work two more new hairy lintless mutants were obtained and therefore included for study.

Results of investigations

Evidence has now been brought forward to show that in addition to five lintless genes already known, two more genes viz. Li_d-li_d [Govande, 1944] and Li_e—li_e, each responsible for hairy lintless effect occur in Asiatic Cottons. This brings the total of the known lintless genes of Asiatic Cottons to seven ; of which four responsible for lintlessness alone (li_a, li_b, li_d and li_e) and two, for lintlessness and glabrous plant body (h_a and h_b), are each complementary to one another for production of normal lint. The present experiments further show that li_a, li_b and li_e are not linked with either L. Lc_1, Y_a or R_2 locus. Li_d—li_d was found to assort freely with R_2.

The gene responsible for lintlessness in the Punjab Hairy lintless, provisionally designated Li_c—li_c by Hutchinson and Gadkari [1937] has been found to be entirely unrelated to the other six lintless genes hitherto known. Its behaviour in crosses with other known lintless genes, its dominance relations and lastly its pleiotropic effects [Ramiah and Kaiwar, 1942] are quite different and as such its designation by the symbol Li_c—li_c which suggests complementary relationship with other lintless members of the series, does not appear to be in order and therefore needs alteration. This lintlessness appears to be due to the action of a gene which brings about a general reduction in the growth rate from flowering time onwards so that the arrest of lint development happens to be one of the expression of this gene.

During the course of these investigations it was noted that in the F_2 of the various crosses which happened to be both inter-racial and interspecific, there was a significant excess of the hairy linted segregates from the ratios expected on the basis of the simple gene segregation. On the basis of available evidence this has now been interpreted as due to the action of a member of the gene complex responsible for lint quantity, behaving as modifier of the hairy lintless genes li_a, li_b and

li_c. In the material dealt with, it appears that a single modifier gene assuming fully linted nature only when present in homozygous condition was involved.

Material

Since the present investigations formed a continuation of the studies initiated by Hutchinson and Gadkari [1937] the lintless types used in these experiments were the ones already described by them. In addition, however, two more new hairy lintless mutants were received and incorporated in the investigations. They were as follows :

(*a*) *Viramgam lintless.* A lintless mutant was recorded at Broach (Gujrat) in the mixed cultures of the discarded breeding material belonging to *Gossypium herbaceum* var. *acerifolium.* It is characterized by a hairy plant body [Ramiah and Paranjpe, 1944] and has a very thick fuzz on the seed. The seed of this mutant was supplied by Sri G. B. Patel, Cotton Breeder, Viramgam to the Economic Botanist, Baroda, who in his turn kindly passed on a few seeds to Indore in 1941.

(*b*) *Nandyal lintless.* This lintless mutant characterized by hairy plant body and fuzzy seed was recorded in a crop of N 14 (*Gossypium arboreum* race *indicum*) at Nandyal by the Cotton Specialist, Madras.

During the course of these experiments two genetic types viz. N 6 and Narrow Kokati were extensively used for determining the linkage relations of the lintless genes. N 6 is a strain of composite ancestry and carried y_a, l_{c1}, n_e, r_2^{os}, while Narrow Kokati belonging to *Gossypium arboreum* race *bengalense* carried L and L_{c1}. In one case a full red type viz. 1056 (carrying R_2^{sr}) belonging to *Gossypium arboreum* race *bengalense* was used.

In addition to the above, a number of standard strains belonging to different taxonomic groups were also used for crossing with different lintless types.

Experiments

(a) *Viramgam lintless*

Govande [1944] suggested that the gene responsible for hairy lintlessness in the Viramgam lintless was the same as Baroda lintless, and designated it as Li_d—li_d. At Indore, Viramgam lintless was crossed to N6 and other lintless types. The details of the F_1 and F_2 behaviour in these crosses are incorporated in the Tables I, II and III. It will be seen from the same that both direct and indirect (wherever F_2 was not available) evidence definitely establishes the fact that lintlessness of the Viramgam lintless was due a simple recessive gene li_d and that it is complementary for lint production to all other hitherto known Asiatic lintless genes except the one in the Punjab hairy lintless (li_c).

(b) *Nandyal lintless*

This hairy lintless mutant was crossed to normal linted N14 (*G. arboreum* race *indicum*) the parent strain wherein it occurred as mutant and to 1027 A.L.F. (*G. herbaceum* var. *acerifolium*). The F_1 in both the cases was normally linted. F_2 showed segregation in linted and lintless classes as follows:

		Linted	Lintless	Total	χ^2	P (n=1)
Nandyal lintless X	N 14	16	8	24	0·89	0.50-0.30
	1027 A.L.F.	33	13	46	0·25	0.70-0.50

Thus it is clear that the lintlessness in Nandyal lintless is due to a single factor difference, normallinted being dominant. It was further crossed to the other hairy lintless genes to ascertain its identity with either of them. Its crosses with li_a, li_b and li_d gave a normal hairy linted plants in F_1 showing thereby that this gene was not only different from them but complementary to them for lint production. Further, absence of its pleiotropic effect on the hairiness of the plant body marked it as different from h_a and h_b. So also its dominance relations and other effects on the plant body marked itself to be different from the Punjab hairy lintless. In the circumstances it is inevitably concluded to be a new gene responsible for hairy lintlessness in Asiatic Cottons and which, in the light of the results of crosses incorporated in Tables I, II and III, may be designated as Li_e—li_e.

(c) *Inter-relations of lin less genes*

Hutchinson and Gadkari [1937] showed that the glabrous lintless genes h_a and h_b were complementary to one another for lint production. They further suggested on the linted nature of the F_1s between different lintless types that li_a and li_b were also complementary for lint production to each other and also with either h_a or h_b. Further data were collected on these crosses. Fresh crosses involving other lintless genes were also made so as to elucidate the inter-relations of all the seven lintless genes hitherto known. The results obtained in different series were as given under:

(i) *Punjab hairy lintless* (li_c li_c). Afzal and Hutchinson [1933] had shown that the Punjab hairy lintless gene was different and nonallelomorphic with h_a. It was therefore crossed to h_b, li_a, li_b, li_d and li_e and the F_1 obtained in each case was hairy lintless. A segregation into linted and lintless classes was obtained in each F_2 the details of which are as given in Table I.

TABLE I

F_1 and F_2 behaviour of the crosses between Punjab hairy lintless and other lintless genes

	Cross	F_1	F_2						
				Hairy lintless	Glabrous lintless	Hairy linted	Total	χ^2	n P.
Punjab Hairy lintless $li_c li_c$—Mollisoni*	$h_b h_b$—mollisoni*	Hairy lintless	Observed	125	53	38	226	0·69	2 0·80—0·70
			Expected (9: 4 :3)	127 1	56·5	42·4	226·0		
	$li_a li_a$-1027 A.L.F.***	do.	Observed	129	..	34	163	0·04	1 0·90—0·80
			Expected (51 : 13)	130	..	33	163		
	$li_b li_b$—(1027 × wagad)F***	do.	Observed	66	..	38	104	17·1	1 Small
			Expected (51 : 13)	83	..	21	104		
	$li_d li^b$(Broach I)***	do.	Observed	13	..	5	18	0.58	1 0·50—0·30
			Expected (51 : 13)	14·3	..	3·7	18·0		
	$li_e li_e$—Nandyal 14**	do.	Observed	30	..	13	43	2·05	1 0·20—0·20
			Expected (51 : 13)	34·2	..	8·8	43·0		

* *G. arboreum* race *bengalense*
** *G. arboreum* race *indicum*
*** *G. herbaceum* var. *acerifolium*

It will be seen from the same that in the cross of this lintless gene carried on *mollisoni* (*G. arboreum* race *bengalense*) back ground with glabrous lintless gene h_b, also carried on mollisoni strain (*G. arboreum* race *bengalense*), there was no segregation of modifiers of lintlessness and a good fit was obtained with the ratio of 9 : 4: : 3 for the hairy lintless, glabrous lintless and hairy linted segregates, expected on the basis of independence and nonallelomorphic nature of the two lintless genes involved. The 125 hairy lintless segregates of this F_2 could be further classified into two categories viz. 45 'downy' lintless having typical phenotypical appearance of homozygous $li_c\ li_c$ and 80 'fuzzy' lintless similar to the expression of the Punjab hairy lintless in heterozygous ($Li_c\ li_c$) condition. The proportion of these classes was in accordance to the expected ratio of 1 : 2.

The crosses of the Punjab hairy lintless gene (li_c) with the other hairy lintless genes viz. li_a, li_b, li_d were interspecific as these were carried on by different strains of *G. herbaceum* var. *acerifolium* and interracial with regard to li_c as it was carried by a parent belonging to *G. arboreum* race *indicum*. The F_1 in each case was phenotypically hairy lintless and F_2 showed a segregation into hairy lintless and hairy linted individuals, the details of which are also given in the Table I.

It will be seen from the same that the ratios for lintless and linted classes in the F_2 of these crosses showed a significant departure from the frequencies expected

on 13 : 3 basis, the linted class being far in excess. This was due to the action of the modifiers of the lintless genes li_a, li_b, li_d and li_e introduced in the cross from the Punjab hairy lintless parents (*G. arboreum* race *bengalense*). The data presented elsewhere show the possibility of single modifier raising the status of lintless segregates (other than due to $li_c\, li_c$ or $Li_c\, li_c$) to the level of linted phenotypes when present in fully homozygous condition. In view of these considerations the expected ratio of lintless and linted segregates in F_2 of these crosses was 51 : 33 and actually a close fit to it was obtained in ale cases except the cross involving li_b. It nevertheless proves beyond doubt the independence and nonallelomorphic nature of the Punjab hairy lintless gene with the lintless genes li_a, li_b, li_d and li_e.

Further, in these crosses the hairy lintless segregates could be clearly classified into two classes viz. downy and fuzzy lintless which were phenotypically similar to the homozygous and hetrozygous phase respectively of the lintless gene li_c. Their proportion was as follows :

Cross		Hairy lintless: Dowyy	Hairy lintless: Fuzzy	Total	X^2 (1 : 2)	P (n=1)
		$li_c\, li_e$ XX XX	$Li_c\, li_c$ XX XX			
$li_c\, li_c$	$li_a\, li_a$	39	90	129	0·56	0·50-0·30
	$li_b\, li_b$	17	49	66	1·70	0·20-0·10
	$li_d\, li_d$	not recorded				
	$li_e\, li_e$	8	22	30	0·60	0·50-0·30

These results clearly show that apart from the independent and nonallelomorphic nature of li_c with other hairy lintless genes it is epistatic to them.

(ii) *Glabrous lintless genes* (*h_a and h_b*) *and the hairy lintless genes* (*li_a, li_b, li_d and li_c*). F_2 data for the crosses between both h_a and h_b with either li_a or li_b is now available the details of which were as follows :

Cross		F2 Hairy lint-ed	Hairy lint-less	Glabr-ous lint-less	Total (39 : 9 : 16)	χ^2	P / n=2
Dharwar G.L**.X h_a h_a	1027 lintless* (li_a li_a)	273	56	137	466	6·37	0·05—0·2
	(1027×waged) lintless* (li_b li_b)	14	2	4	20	0·68	0·80—0·70
Punjab G. L*. X h_b h_b	1027 lintless* (li_a li_a)	218	47	91	356	0·23	0·70—0·50
	1027×waged lintless* (li_b li_b)	10	3	2	15	1·31	0·70—0·50

* *G. herbaceum*-var. *acerifolium*
** *G. arboreum* race *bengalense*

In view of the suggested complementary nature of these genes on the basis of the linted nature of F_1, reported by Hutchinson and Gadkari [1937], it was expected that the F_2 segregation would agree to 9 : 3 : 4 pattern. However taking into consideration the interspecific nature of the crosses and the consequent modifier action of the '*bengalense*' lint quantity genes on li_a and li_b in the way suggested previously and discussed in detail later on, the expected ratio in these crosses was 39 : 9 : 16. A good fit to this has been obtained confirming thereby the complementary nature of these lintless genes for lint production.

Regarding the relationship of the glabrous lintless genes with li_d, and li_e, Govande [1944] and Ramnathan [1937] have shown that the F_1 hybrids between h_a and h_b on one hand and li_d and li_e on the other, were all hairy linted. This fact also indicates that these lintless genes are also complementary to h_a and h_b for lint production.

(iii) *Relationship of the other hairy lintless genes.* Hutchinson and Gadkare [1937] had pointed out the complementary nature of li_a and li_b on the basis of the linted F_1 between them. Subsequently F_2 of this cross was grown together with the F_1s and F_2s of the crosses $li_a \times li_d$, $li_a \times li_e$, $li_b \times li_d$, $li_b \times li_e$, and $li_d \times li_e$. The F_1 plants of all these crosses were normally hairy linted and the F_2 segregated into linted and lintless classes, the actual frequencies of which are given in Table II.

TABLE II

F_2 segregation in crosses involving different hairy lintless genes (except Punjab H. L.)

Cross		Hairy linted	Hairy lintless	Total	χ^2 (9 : 7)	P
$li_a li_a$ ×	$li_b li_b$	42	32	74	0·01	0·95—0·90
	$li_a li_a$	No germination				
	$li_e li_e$	24	23	47	0·52	0·50—0·30
$li_b li_b$ ×	$li_d li_d$	69	49	118	0·11	0·80—0·70
	$li_e li_e$	39	32	71	0·08	0·80—0·70
$li_d li_d$ ×	$li_c li_c$	38	31	69	0·03	0·90—0·70

The ratios for the linted and lintless classes given in Table II show a close agreement to the expected 9 : 7 showing there by the complementary nature of these lintless genes for lint production. It was also mentioned that in these crosses there was no disturbance of the ratios due to the lint quantity modifiers.

(*d*) *Modifiers of lintlessness*

It was noted in the early stages of this investigation that in a number of crosses involving the different hairy lintless genes there was often a large deficiency of the hairy lintless class from the values normally expected on the basis of the segregation of the lintless genes alone. This has now been explained as being due to the action of the lint quantity genes of different strains acting as modifier of the hairy lintless gene, raising the homozygous lintless to the full linted condition when present in homozygous phase. This assumption was based on the results of the studies carried out on a few crosses-by growing their F_3 progenies. The results of which were as follows :

(i) *Nandyal lintless* li_c li_e (*G. arboreum* race *indicum*) × *Narrow Kokati*—*Li_e Li_e*—*G. arboreum* race *bengalense*). The F_1 of this cross was normal linted and the F_2 segregated into 113 linted and 23 lintless plants showing thereby a significant shortage of the hairy lintless segregates on the basis of simple Li_e—li_e segregation on 3 : 1 basis (χ^2=4·7, P=0·05—0·02). F_3 was grown from 45 linted and 11 lintless segregates and it was found that out of the eleven F_3 progenies obtained from F_2 lintless segregates four bred true to lintlessness and seven segregated again into linted and lintless individuals. The pooled total for the two classes for these seven segregating progenies was 50 linted : 153 lintless showing good fit to 1 :3 ratio (χ^2=0·23, n=1, P=0·70-0·50). This position suggested that not only a number of lintless segregates of the F_2 were heterozygous for lint quantity modifier, which when bred to homozygosity became fully linted but it also involved that a definite proportion

of the lintless (li_a li_a) segregates of F_2 must become linted and classed as such. The whole position became clear when it was realised that a number of the lint quantity gene complex carried by the Narrow Kokati parent (*G. arboreum* race *bengalense*) behaved as modifier of li_c and raised the li_e li_e segregates to fully linted condition when present in homozygous condition. The symbolic behaviour of the cross would therefore be as follows :

Li_e Li_e + + × li_e li_e — — Parents

Li_e li_e + — F_1

F_2

13 Linted
*1 Li_eLi_e+ +
*2 Li_eLi_e + —
*1 Li_eLi_e — —
*2 Li_eli_e +
*4 Li_eli_e + +
***2 Li_eli_e— —
*1 li_eli_e +

3 Lintless
@2 li_eli_e + —
@@ 1 li_eli_c — —

* Giving all linted in F_3
** Giving in F_3 linted and lintless in 13 : 3 ratio
*** Giving in F_3 linted and lintless in 3 : 1 ratio
@ Giving in F_3 linted and lintless in 1 : 3 ratio
@@ Giving all lintless in F_3

The observed behaviour of this cross agrees very closely with the above scheme. The F_2 segregation of 113 linted 23 lintless shows a good fit to 13 : 3 ratio (χ^2= 0·30, n=1, P=0·70-0.50). F_3 grown consisted of 56 progenies coming from as many F_2 plants. Their classification on the basis of their breeding behaviour was as follows :

	F_2 Parent linted		F_2 parent lintless		
	Giving all lintless	Segregating to linted and lintless individuals	Segregating into linted and lintless individuals	Giving all lintless segregates	Total
Observation . .	14	31	7	4	56
Experiment (7 :5 : 2 : 1)	24·5	21	7	3·5	56

χ^2=9·5 ; n=3 ; P=0·05—0·02

Owing to insufficient population in each individual segregating family it was difficult to decide the type of segregation i.e., 13 : 3 or 3 : 1 for each. However pooled frequencies of these classes for the segregating families coming from either linted or lintless parent were as follows :

(i) Pooled segregation for F_3 families obtained from linted F_2 plants :

	Linted	Lintless	Total
Observation	366	81	447
Experiment (19 : 5) . . .	354	93	447

[4(13: 3)+2(12 : 4)]
X^2=0·41 : n=1 ; P=0·70—0·50

(2) Pooled segregation of the F_3 progenies grown from lintless parents :

	Linted	Lintless	Total
Observation	55	153	208
Experiment (1 : 3)	52	156	208

χ^2=0·23 ; n=1 ; P=0·70—0·50

(ii) (1027 *A.L.F. lintless*, li_ali_a × *Narrow Kokati* Li_aLi_a) × 1027 *A.L.F. lintless*, li_ali_a :—The back cross progeny of this cross gave 19 linted and 17 lintless plants showing a good fit to the expected 1 : 1 ratio (χ^2=0·11 ; n=1 ; *P*=0·80—0·70). Progenies were grown from the selfed seed obtained from these segregates. Sixteen progenies were available from the linted individuals and it was noted that all of these showed a segregation again into linted and lintless class. The pooled frequencies for them were 124 linted : 30 lintless, showing a good fit to the expected ratio of 25 : 7 [(13 : 3)+(22 : 4)] χ^2=0·52 ; n=1 ; *P*=0·50—0·30. Four progenies grown from lintless segregates gave a pooled total of 8 linted : 12 lintless plants, a good fit to the expected 1 : 3 ratio (χ^2=2·4 ; n=1 ; *P*=0·20—0·10).

The symbolic representative of this cross would be as follows :

li_ali_a — — X Li_aLi_a + +
(1027 A.L.F. lintless) (Narrow Kokati linted)

Li_ali_a + — × li_ali_a — —
F_1 (1027 A.L.F. lintless)

1 Li_ali_a + —
1 Li_ali_a — —
} linted *

1 li_ali_a + —
1 li_ali_a — —
} lintless **

* The linted segregates will on breeding give linted and lintless plants, half of the progenies giving 13 :3 ratio and other half 3 : 1 so that the total pooled segregation would be in 25 : 7 i.e. (13 : 3 + 12 : 4) ratio.

** Of the lintless segregates half (li_ali_a — —) would breed to lintless whereas the other half (li_ali_a + —) would segregate into linted and lintless individuals in 1 : 3 ratio.

The data presented above has shown that the actual results obtained are in conformity with the expectation on the above scheme of things.

(iii) Further evidence for the existence of the modifier action of a member of lint quantity gene complex towards disturbing the normal ratio of hairy linted and hairy lintless was available from the results of the cross between two lintless types viz., 1027 A.L.F. lintless (li_ali_a) and Dharwar glabrous lintless the details of whose expected and actual behaviour were as follows :

(1) The two lintless parents viz. Dharwar glabrous lintless (*G. arboreum* race *bengalense*) and 1027 A.L.F. lintless (*G. herbaceum* var. *acerifolium*) were respectively $Li_aLi_ah_ah_a$ + + and $li_ali_aH_aH_a$ — —. The modifier under reference carried by Dharwar glabrous lintless being hypostatic to h_ah_a. The F_1 of these two lintless types was normal linted being $Li_aLi_aH_aH_a$ + —.

(2) F_2 grown out of $Li_ali_aH_ah_a$ + — would segregate into three phenotypic classes viz., 39 hairy linted ; 9 hairy lintless and 16 glabrous. (The glabrous lintless segregates hardly bear seed at Indore due to the rigorous climatic conditions prevalent at the place). These three phenotypic classes of F_2 were made up various genotypic combinations which, in F_3 would behave differently, were as follows :

39 Hairy linted normal :

1 $Li_aLi_aH_aH_a$ + + 2 $Li_aLi_aH_aH_a$ + — 1 $Li_aLi_aH_aH_a$ — — 2 $Li_ali_aH_aH_a$ + + 1 $li_ali_aH_aH_a$ + +	Giving all hairy linted in F_3
4 $Li_ali_aH_aH_a$ + —	Giving hairy linted and lintless in 13 : 3 in F_3
2 $Li_ali_aH_aH_a$ — —	Giving hairy linted and hairy lintless in 3 : 1 in F_3
2 $Li_aLi_aH_aH_a$ + + 4 $Li_aLi_aH_ah_a$ + — 2 $Li_aLi_aH_ah_a$ — — 4 $Li_ali_aH_ah_a$ + + 2 $li_ali_aH_ah_a$ + +	Giving hairy linted and glabrous in 3 : 1 in F_3
4 $Li_ali_aH_ah_a$ — —	Giving hairy linted, hairy lintless and glabrous in F_3 in 9 : 3 : 4.
8 $Li_ali_aH_ah_a$ + —	Giving hairy linted hairy lintless and glabrous lintless in 39 : 9 : 16 in F_3

9 Hairy lintless :

2 $li_a li_a H_a H_a$ + —	Giving linted to lintless in 1 : 3 in F_3
1 $li_a li_a H_a H_a$ — —	Giving all hairy lintless.
4 $li_a li_a H_a h_a$ + —	Giving hairy linted, hairy lintless and glabrous (3 : 9 : 4).
2 $li_a li_a H_a h_a$ — —	Giving hairy lintless and glabrous (3 : 1).

16 Glabrous :

1 $Li_a Li_a h_a h_a$ + +	Giving all glabrous plants in F_3
2 $Li_a Li_a h_a h_a$ + —	
1 $Li_a Li_a h_a h_a$ — —	
2 $Li_a li_a h_a h_a$ + +	
4 $Li_a li_a h_a h_a$ + —	
2 $Li_a li_a h_a h_a$ — —	
1 $li_a li_a h_a h_a$ + +	
2 $li_a li_a h_a h_a$ + —	
1 $li_a li_a h_a h_a$ — —	

Actually the F_2 frequencies for the cross, as given elsewhere, were 273 hairy linted, 56 hairy lintless and 137 glabrous giving a close fit to 39 : 9 : 16 ratio, $\chi^2 = 6{\cdot}37$; n=2 ; P=0·05 —0·02, F_3 families were grown from both hairy linted and hairy lintless individuals. However, the size of individual F_3 families was small and as such it was difficult to decide which type of segregation was involved. The progenies obtained from hairy linted individuals could be classed either as (1) breeding true for linted nature, or (2) segregating into (a) hairy linted and hairy lintless individuals (b) segregating into hairy linted and glabrous individuals or (c) segregating into hairy linted, hairy lintless and glabrous individuals. The pooled segregation for the families belonging to each of the above category was as follows :

(*a*) Segregating into hairy linted and hairy lintless individuals.

	Hairy linted	Hairy lintless	Total
Observed	1062	279	1341
Expected (19 : 5) [4 (13 : 3) + 2 (12 : 4)]	1061·7	279·5	1341

$\chi^2 = 0{\cdot}00$; n=1 ; *P*=very large

(*b*) Segregating into hairy linted and glabrous individuals

	Hairy linted	Glabrous individuals	Total
Observed	537	209	746
Expected (3 : 1)	559·5	186·5	746

$\chi^2 = 3{\cdot}61$; n=1 ; *P*=0·10—0·05

(*c*) Segregating into hairy linted, hairy lintless and glabrous individuals

	Hairy linted	Hairy lintless	Glabrous	Total
Observed	246	72	114	432
Expected (19 : 5 : 8) [4 (9 : 3 : 4) + (39 : 9 : 16)2]	256·5	67·5	108	432

χ^2=1·05 ; n=2 ; P=0·70—0·50

Four F_3 progenies were grown from the hairy lintless segregates of F_2. Of these two failed to germinate and two segregated into hairy linted and hairy lintless classes as follows :

	Hairy linted	Heiry lintless	Total
Observed	8	12	=20
Expected (1 : 3)	5	15	=20

χ^2=2·4 ; n=1 ; P=0·20—0·10

The above agreement of the experimental data with the expected behaviour proves the validity of the assumptions made above. It may however be mentioned that although the foregoing results have been interpreted on the basis of a single modifier gene giving a fully linted condition when present in homozygous condition, the effect of the modifier gene is of quantitative nature. It was noted in the most segregating families that there was present varying degrees of lint quantity on the seed in different plants which were confidently classed as lintless. This aspect of the quantitative action of the modifier was not investigated in detail as the scope of the present investigations was confined to the behaviour of lintless genes alone.

(e) *Linkage relations of lintless genes*

Hutchinson [1935] and Hutchinson and Gadkari [1937] studied the linkage relations of h_a, h_b and the Punjab hairy lintless (li_c) with other known loci in Asiatic cottons. Information regarding the linkage relations of the hairy lintless genes li_a, li_b, li_d and li_e was obtained by crossing them to normal linted types like Narrow Kokati, N6 and 1056. Furthermore, information pertaining to the linkage or otherwise of h_b and Punjab hairy lintless (li_c) genes with anthocyanin locus R_2 not reported by Hutchinson and Godkari [1937] was also collected.

Two factor segregations in F_2 and the back cross progenies of different crosses have been detailed in the Table III. It will be seen from the same that Li_a—li_a, Li_b—li_b and Li_e—li_c factor pairs assort freely with L—l, Lc_1—lc_1, R_2—r_2 and Y_a—y_a and as such there is no evidence of linkage between them. In these crosses, however, where lint colour and leafshape segregations were involved the expected linkage with 30 to 33 per cent cross over was obtained between the L—l and Lc_1—lc_1 loci [Hutchinson, 1935]. Further-more it was noted that Li_d—li_d, H_b—h_b and Punjab hairy lintless gene Li_c—li_c assorted freely with R_2 and as such not linked.

Discussion

Ten lintless mutants have been so far reported in Asiatic cottons and studies have shown that these have been due to seven independent genes mentioned above. All of these were primarily characterized by the absence of normal lint development on the seed ; three of them, however, happened to effect other plant characters as pleiotropic effects.

Table III

Two factor ratios in crosses involving the different lintless genes with normal linted type

(a) *Lintless genes X (narow Kokati (G. arboreum race bengalense)*

Lintless parent	Generation	Lintlessness	Hairy linted X	Hairy linted x	Hairy lintless X	Hairy lintless x	Total	χ^2 Lintless (13 : 3)	χ^2 and 3 : 1	χ^2 (L)
li_a	F_2	L—l	12	3	5	2	22	2·52	0·06	0·25
,,	$F_1 \times$	,,	9	10	6	9	34	0·47	0·47	0·12
,,	F_2	Lc_1—lc_1								
,,	$F_1 \times$	,,	12	7	8	7	34	0·47	1·01	0·41
li_b	F_2	L—l	586	235	199	64	1084	0·31	1·39	1·98
,,	,,	Lc_1—lc_1	581	238	—	—	819	—	7·20	—
li_c	F_2	L—l	81	31	14	9	135	0·30	1·54	1·10
,,	,,	Lc_1—lc_1	87	26	15	8	136	0·30	0·00	1·15
(b) *Lintless genes X N6 and 1065*										
li_a	F_2	RS AS R_2—R_2	38	15	10	3	66	0·07	0·18	0·07
	F_2	AS OS R_2—R_2	16	8	6	1	31	0·30	0·27	1·02
	,,	Y_a—y_a	16	8	7	—	31	0·30	0·09	3·54
li_b	F_2	AS OS R_2—R_2	246	69	56	17	388	0·00	1·65	0·07
	,,	Y_a—y_a	231	76	58	15	380	0·21	0·22	0·43
li_d	F_2	AS OS R_2—R_2	35	11	5	4	55	0·20	0·15	0·41
li_c	F_2	AS OS R_2—R_2	8	2	5	1	16	3·69	0·33	0·25
	,,	Y_a—y_a	9	1	4	2	16	3·69	0·33	1·54

(c) *Punjab glabrous lintless (h_b—h_b) × 1056*

		H y l d RS R_2	H y l d AS R_2	Glabrous lintless RS R_2	Glabrous lintless AS R_2	Total	χ^2 H_a—h_a	χ^2 RS AS R_2—R_2	χ^2 (L)
h_b ..	F_2	206	83	70	18	377	0·55	0·64	2·08

TABLE III—*contd.*

Two factor ratios in crosses involving the different lintless genes with normal linted types —contd.

(d) Punjab hairy lintless (li_c li_c) × 1056

		Normal linted		Short lint		lintless		Total
				li_c	li_e			
		RS	AS	RS	AS	RS	AS	
		R_2	R_2	R_2	R_2	R_2	R_2	
li_c	F_2	87	27	42	38	61	20	375

$\chi^2=7{\cdot}92$; $n=5$; $p=0{\cdot}20$—$0{\cdot}10$

The data collected hitherto have shown that h_a, h_b, li_a, li_b, li_d and li_e are complementary to one another for lint production. The seventh gene viz., the one involved in Punjab hairy lintless designated li_c [Hutchinson and Gadkari, 1937] is now found to be totally unrelated to the other six genes and it appears doubtful whether the gene symbol Li_c—li_c [Hutchinson and Gadkari, 1937, Silow, 1939] which suggests membership of the series Li_a—li_a Li_c—li_c should be retained. Data presented by Ramiah and Gadkari [1941] to explain the causes responsible for change from full lethality of homozygous lintless [Afzal and Hutchinson, 1934] to full viability and abnormal behaviour of leafshape distribution of F_2 of its cross with narrow Kokati [Hutchinson and Gadkari, 1937] together with the studies of Ramiah and Kaiwar [1944] on the pleiotropic effects of this lintlesss show that the action of this gene particularly when present in homozygous condition happens to be that of reducing the general growth rate of the plant organs and finally arresting the elongation of the epidermal cells of the seed which go to from the lint. The gene symbol should be suggestive of this general action of the gene and not one indicating one of its many end manifestations. However new nomenclature for the same is deferred to some later date pending detailed work on other lintless genes.

The genes h_a and h_b in addition to their lintless nature bring about total absence of hair on the plant body, showing thereby that they control the development of the total hairiness mechanism of the plant body including that on the seed and thereby making the plant lintless. This however is not the position with li_a, li_b and li_e where the gene action controls the hair development on the seed alone or in other words effects lint production only. The Viramgam lintless (li_d) was characterized by the presence of stellate hair on its plant body. This however was not a pleiotropic effect of the gene li_e but due to h_s [Ramiah and Paranjpe, 1944].

The present investigations have also shown the existence and the role of modifiers of the hairy lintless genes Silow [1939] showed that the members of gene complex controlling lint quantity behaved as modifier of lintless and that he was able to class them into epistatic and hypostatic series in relation to h_a. It was further pointed out by him that these epistatic and hypostatic series of lint quantity genes

followed a varietal and specific distribution, the former being present in *G. arboreum* race *indicum*, *G. arboreum* race *sinense* and *G. herbaceum* var. *acerifolium* and the latter existed in the *G. arboreum* race *bengalense*, *G. arboreum* race *burmanicum* and *G. arboreum* race *cernuum*. In the present series of experiments modifier action was effective; and disturbed segregations involving the hairy lintless genes li_a, li_b, li_d which were mutants in *G. herbaceum* var. *accrifolium*, and li_e a mutant in *G. arboreum* race *indicum*. It was suggested at the onset that the lintless mutants-li_a, li_b, li_d and li_e would be normally epistatic to the series epistatic to h_a and probably not to the hypostatic series of Silow [1940] carried by *G. arboreum* race *bengalense* and *G. arboreum* race *burmanicum*, wherein h_a and appeared as mutant, and therefore it was likely that when these lintless types were crossed to *G. arboreum* race *bengalense* or *burmanicum*, the lint quantity complex carried by them and hypostatic to h_a would assume the role of epistatic modifier to these hairy lintless genes. However, in absence of any direct evidence regarding the identity of the modifiers encountered in the above crosses and the hypostatic series h_a of Silow [1940], the above suggestion cannot be accepted. Further, the absence of modifier segregation in the cross li_b × narrow Kokati (*G. arboreum* race *bengalense*) and modifier segregation encountred by Patel *et al* [1946] in the cross between li_b and G.A. 26 (both belonging to *G. herbaceum* var. *acerifolium*) suggest the possibility of the modifiers of the different hairy lintless genes being different and also different from the hypostatic series of Silow [1940]. It is however clear that future detailed work alone would not only throw light on the behaviour and relationship of these modifiers but would help to understand the genetic make up of the lint quantity and ginning percentage of the different varieties of cultivated Asiatic cottons.

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INVESTIGATIONS ON THE 'BAD OPENING' OF BOLLS IN SIND-AMERICAN COTTON IN SIND.

II. OPTIMUM SOWING PERIODS FOR COTTON*

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It was reported in the previous contribution‡ that by late sowing of the 'cotton crop' the damage caused by the ' bad opening ' of the bolls could be greatly reduced [Dastur, 1949]. It was also observed that the yellowing and reddening of the leaves on light sandy lands did not occur at all or occurred to a lesser extent in the late sown crop than in early sown crop. In order to reduce the damage caused by ' bad opening ' and the red leaf disease it was important to know how far and to what extent this measure of late sowing can be practised. It was shown in the investigations conducted in the Punjab [Dastur and Mukhtar Singh, 1942] that the late sown crop suffered from a serious disadvantage of a reduction in bearing on account of a reduction in vegetative growth caused by a delay in sowing. This defect was partially counteracted by adoption of closer spacing than the normal practice of 3 ft. between rows and $1\frac{1}{2}$ ft. between plants. It was, therefore, necessary to determine how far the sowings of cotton in the different tracts in Sind could be delayed so as to minimize the damage caused by ' bad opening ' of bolls and the red leaf blight without in any way reducing the yields by a decrease in bearing. The optimum sowing periods for cotton in the different tracts during which highest yields were obtained had, therefore, to be determined by adopting the measure of closer spacing between plants.

The first reference to the optimum sowing period for cottons in Sind was found in the final report of the Sind Physiological Scheme financed jointly by the Sind Government and the Indian Central Cotton Committee from 1927 to 1937. The recommendations for cotton sowings were based on the sowing date experiments conducted in the Scheme. It is stated on p. 59 of the report written by Sankaran [1938] : ' If due weight is given to these results it would appear that April has been the optimum sowing period during all years and can therefore be recommended. It must, however, be remembered that the results are applicable to middle Sind (Nawabshah district in which Sakrand is situated). In South and East Sind (Hyderabad and Tharparkar districts) which are characterized by milder climate the sowings may have to be earlier '.

The above recommendations have not been adopted, as the departmental recommendations as given in the *Departmental Leaflet No.* 48 (2nd Edition, 1943)

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were entirely different and were apparently based on the experiments conducted by the departmental staff. The recommendations for sowing cotton for these tracts were (i) Jamrao Tract (East Sind)—end of March to end of April; (ii) Hyderabad Tract (South Sind)—15th April to 15 May and (iii) North and Middle Sind—15 May to 15 June.

Experimental

In all previous experiments conducted in Sind spacing was not included as a separate factor for study in the sowing date trials. It is recommended to sow cotton at a distance of 3 ft. between rows irrespective of sowing date in the sowing period. It would be shown below that May-sowings in Hyderabad and June-sowings in Middle Sind should be done closer than at 3 ft. distance to give maximum yields. It was, therefore, necessary to include different spacings in the sowing date experiments that were primarily conducted to determine how far sowings of cotton could be delayed so as to minimize ' bad opening ' and to give the highest outturn per acre.

Four types of factorial experiments were conducted during the period 1943 to 1946 :

(1) Some experiments were sowing date-cum-varietal experiments. In view of the established relationship between sowing date and spacing in the Punjab experiments [Dastur, Mukhtar Singh and Sucha Singh, 1944], the spacing was gradually reduced from 3 ft. between rows to $2\frac{1}{2}$ ft., 2 ft. and $1\frac{1}{2}$ ft. as the sowing date advanced. Side by side, the relationship between sowing date and spacing was tested in Sind in the second set of experiments.

(2) Ten experiments (Nos. 12, 14, 15, 22, 23, 26, 32, 35, 36 and 37) were of the sowing date-cum-varietal-cum-spacing types in which spacing was included as a separate factor.

(3) Some experiments (Nos. 11, 24 and 31) were of a sowing date-cum-variety-cum-manuring type to study the relation of sowing date in relation to manuring on yield.

(4) Some experiments (Nos. 4, 18 and 27) were of a sowing-date-spacing-varietal-manuring type to study the interaction of all factors on yield.

It would take too much space to discuss the results of each experiment separately so the detailed results of four experiments from different tracts are given below in Table I, to demonstrate the interrelation of sowng date with variety, though they contained other factors also. We are concerned with the optimum sowing periods for cotton as judged from the level of the yields so the main effects of sowing dates on yields are alone important.

At Mirpurkhas the optimum sowing period seemed to be between 30 April and 10 June but this was not supported by other experiments conducted in the same area when early June sowings gave very low yields (Table IV). The same remarks applied to other tracts. At Denisar in East Sind the optimum sowing period as shown in Table I appeared to be between 6 April and 30 April but in other experiments

conducted in the same tract May-sowings gave higher yields (Table IV). At Hyderabad the optimum sowing period in Table I appeared to be between 30 April and 11 June while at Sakrand it was found to be between 14 May and 27 July. In deciding upon the optimum sowing periods the results of all the experiments conducted in each tract will have to be considered.

Table I

Yield in maunds per acre under different sowing dates in different tracts*

Experiment No. 12 — Mirpurkhas (1943) (East Sind)

Variety	Sowing date: 9 April	30 April	20 May	10 June	Mean (+0·34)
M4	16·2	19·5	20·5	18·8	*18·7*
Sind Sudhar	10·3	13·0	18·4	13·6	*13·8*
Hybrids	5·0	7·9	13·7	8·8	*8·8*
Mean (±0·52)	*10·5*	*13·5*	*17·5*	*13·8*	

Experiment No. 5 — Denisar Estate (1945) (East Sind)

Variety	Sowing date: 6 April	25 April	15 May	6 June	Mean (±0·40)
M4	15·0	17·0	13·0	8·0	*13·3*
L.S.S.	13·6	14·1	12·0	6·6	*11·6*
289F/124	13·7	14·6	10·8	4·6	*10·9*
289F/199	11·2	15·2	12·3	7·0	*11·4*
Cambodia	12·8	13·9	10·4	4·6	*10·4*
Mean(±0·93)	*13·3*	*15·0*	*11·7*	*6·2*	

Experiment No. 20 — Hyderabad (1945) (South Sind)

Variety	Sowing date: 30 April	21 May	11 June	Mean (±0·46)
M4	23·5	21·9	25·6	*23·6*
Sind Sudhar	17·2	18·5	17·8	*17·8*
L. S. S.	15·5	18·6	21·7	*18·6*
289F/124	20·3	19·3	17·0	*18·9*
289F/199	16·7	17·5	18·4	17·5
Mean (±1·09)	*18·6*	*19·2*	*20·1*	

Experiment No. 24 — Sakrand (1943) (Middle Sind)

Variety	Sowing date: 14 May	3 June	24 June	17 July	Mean (±0·51)
M4	12·6	12·2	13·3	12·9	*12·7*
Sind Sudhar	10·7	10·1	11·4	12·1	*11·1*
289F/K25	11·3	11·0	13·2	12·3	*12·0*
289F/124	11·1	11·1	13·1	12·3	*11·9*
Mean(±0·98)	*11·4*	*11·1*	*12·7*	*12·4*	

* One maund = 82·2 lb.

The main difficulty in field experimentation that was encountered in Sind was the ununiform stand of the crop in the plots. It was difficult to get an uniform stand in all experimental plots. In some experiments half of the total experimental area was devoid of plants. The chief factors that produced gappiness were white ants, root rot and saline patches. It was also considered not very accurate to make suitable corrections for stand by adopting standard methods as the plants in and

bordering the gaps produced very vigorous growth which they would not do, had they been surrounded on all sides by other plants. As the gaps were too many; population showing such abnormal growth was great. Such experiments were not considered in deciding upon the optimum sowing period even though the yields were collected.

The differential effect of nitrogen and spacing on sowing date

In deciding upon the optimum sowing periods for cotton, the differential effect of sowing date with manuring and of sowing date with spacing will have to be considered in the different sowing-date-cum-manurial and sowing date-cum-spacing experiments. The early sowings profited more by manuring than late sowings. The magnitude of the increase in yield under different sowings is found to decline as the sowings are done later. In Table II the results of one experiment are given to illustrate the point.

In such a case the mean yield of the unmanured and manured plots would give an earlier optimum, from 23 March to 20 April than if the mean yields of the unmanured plots under four sowing dates are taken where the optimum period seemed to be between 6 April and 4 May. Thus, the optimum sowing period would differ in the case of manured and unmanured fields. In such cases the optimum sowing period for unmanured crop was taken in arriving at general conclusions.

TABLE II

Yield in maunds per acre

Experiment No. 1, Denisar Estate (1943) — Sowing date × manuring

Sowing date	23 March	6 April	20 April	4 May	Mean (±0·50)
Manured	18·1	19·1	17·0	14·5	17·2
Control	11·7	13·5	14·1	13·2	13·1
Mean (±0·76)	*14·9*	*16·3*	*15·6*	*13·9*	*15·2*

Experiment No. 12, Mirpurkhas (1943) — Sowing date × spacing

Spacing between rows	9 April	30 April	28 May	10 June	Mean (±0·68)
3 ft.	9·8	13·0	16·0	10·8	12·7
2½ ft.	11·2	13·8	19·2	14·0	14·5
2 ft.	11·1	13·8	16·7	13·1	13·7
1½ ft.	9·9	12·7	17·6	16·9	14·3
Mean (±0·52)	*10·5*	*13·3*	*17·3*	*13·7*	

The yields of earlier sowings were found to be unaffected under closer spacings in sowing date-spacing experiments while the yields of later sowings were lower under wider spacings than under close spacings. The mean yield of later sowing which was an average of the yields under all spacings would be lowered to a small extent and became less than what they were under closer spacing alone (Table II). So, in deciding upon the optimum sowing period, the yield of later sowings with close spacings alone were considered in the sowing date-spacing experiment of this type.

As late sowings remedied *tirak* it was necessary to plant crop as late as possible so that *tirak* may not occur but at the same time the yields should not be reduced. Thus, close spacing was necessary. It was, therefore, necessary to determine optimum spacing for each fortnight of the sowing period.

The effect of spacing on yields under different sowings

The spacing was kept as a separate factor for study in 9 experiments (Nos. 12, 15, 18, 22, 23, 26, 35, 36 and 37), as preliminary trials brought out the necessity of closer spacing for crops sown later in the sowing period (Table II). In experiment No. 12 given in Table II four different spacings were kept and it was found that three feet distance proved even too wide for the early sowings done on 9 April. It was found that close spacing of 1½ ft. between rows gave higher yields than wider spacings in the last two sowings. It was, therefore, undertaken to include three spacings, wide=3 to 2½ ft. between rows; medium=2½ to 2 ft. between rows and close=2 to 1½ ft. between rows. The plant to plant distance was kept half the row to row distance. These trials were conducted at Mirpurkhas, Oderolal and Pad Idan. The results of four experiments conducted at Oderolal and Mirpurkhas repeated in two years are given below. Sowing date into spacing interaction was not significant in any of these experiments.

TABLE III

Yields in maunds per acre

Experiment No. 22 — Oderolal (1945-46)

Spacing	5 May	17 May	2 June	16 June	Mean (±1·21)
Wide	18·8	18·8	18·6	16·2	*18·2*
Medium	21.6	21·0	17·4	17·0	*19·2*
Close	21·0	23·7	19·1	19·3	*20·8*
Mean (±1·77)	*20·5*	*21·2*	*18·4*	*17·5*	

Experiment No. 23 — Oderolal (1946-47)

Spacing	19 April	4 May	19 May	3 June	Mean ±(0·33)
Wide	18·0	10·0	9·4	13·1	*12·8*
Medium	16·0	13·1	12·4	14·0	*13·9*
Close	14·3	11·8	11·0	15·9	*13·0*
Mean (±0·99)	*16·1*	*11·7*	*11·1*	*14·1*	

Experiment No. 14 — Mirpurkhas (1945-46)

Spacing	3 May	18 May	31 May	14 June	Mean (±0·72)
Wide	14·9	14·8	10·4	5·9	*11·5*
Medium	17·6	16·3	12·4	6·7	*13·3*
Close	18·4	16·4	14·4	11·4	*15·2*
Mean (±1·19)	*17·0*	*15·8*	*12·11*	*8·0*	

Experiment No. 15 — Mirpurkhas (1946-47)

Spacing	8 April	24 April	8 May	25 May	Mean (±0·47)
Wide	13·4	13·9	14·5	14·1	*14·0*
Medium	13·8	13·9	15·0	14·9	*14·4*
Close	14·6	15·1	15·0	15·1	*15·0*
Mean (±0·88)	*13·9*	*14·3*	*14·8*	*14·7*	

In Experiment No. 22 of 1945-46 close spacing gave significantly higher yields than medium or wide spacing in the mid-May. The difference between close and wide spacings was not significant in the third sowing. So, for the first sowings medium spacing was optimum while for the last three sowings close spacing proved to be optimum. The optimum sowing period for Oderolal (Hyderabad district) appeared to be between 5 May and 2 June when the crop was closely spaced and the sowing period can be extended to 16 June without further decreasing the yield.

In Experiment No. 13 of 1946-47 arranged at the same place the results obtained were complex as the two middle sowings gave lower yields than the two end sowings owing to the presence of *kalar* patches. In this case wide spacing proved to be optimum for the first sowing, medium spacing proved optimum for the two middle sowings and close spacing proved optimum for the last sowing. In the first sowing wide spacing gave significantly higher yield than the medium or close spacing, while in the fourth sowing close spacing gave significantly higher yield.

In Experiment No. 14 of 1945-46 conducted at Mirpurkhas the maximum yields were obtained under close spacing in all the four sowings. Thus, close spacing was even found to be necessary for early sown crop but more so for the late sown crop where close spacing gave significantly higher yields than wide or medium spacings. Thus, close spacing again proved to be necessary for the crop sown in the second half of the sowing period.

In experiment No. 15 of 1946-47 conducted at Mirpurkhas the trends in yields were again similar to those discussed above for Experiment No. 14. The maximum yields were obtained by adoption of close spacing under all sowing dates.

Thus, close spacing was found necessary to obtain maximum yields even in early sowings in three experiments out of four discussed above while it was found necessary for the late sown crops in all the four experiments.

The trends in the remaining five experiments were similar to those discussed above. It would be advantageous if the spacing between rows was reduced for the crops sown later though in some cases even closer spacing alone proved advantageous to early sown crops. The present recommendation to the *zamindars* in Sind is to plant crop at 3 ft. distance irrespective of sowing time and it would be seen from the above that closer spacing would give varying increases in yields for the crop sown later in the sowing period.

In Experiment Nos. 4, 18, 26 and 27 only two spacings were kept as treatments in combination with two sowing dates and two levels of manuring and three varieties. It was a common experiment laid out at different places in Sind. The results obtained were similar to those discussed above. Close spacing was found advantageous for the late sown crop.

Yields under different sowings in all experiments

It is not the object of this paper to discuss each and every experiment conducted in Sind as there is nothing new in the results obtained. The main object was to determine the sowing period that gave maximum yields of cotton and at the same

time reduced the damage caused by 'bad opening' of bolls by sowing as late as possible in combination with close spacing.

In all, 38 complex experiments were conducted in Sind and were laid out in five tracts : (i) South East Tharparkar ; (ii) North East Tharparkar ; (iii) Hyderabad (iv) Middle Sind and (v) North Sind to determine small differences in the optimum; sowing periods even in the different parts of the same tract. Some of the experiments were conducted by the departmental staff under the guidance of the author. Out of the 38 experiments, eight experiments had to be rejected on account of the reasons stated above. These experiments were, therefore, not considered and are omitted.

The mean yield averaged for all treatments under each sowing date with standard error for each experiment is given in Table IV. The year and the name of the place where the experiment was conducted are also given.

TABLE IV

Mean yields in maunds per acre under different sowing dates in Sind (1943-46)

Experiment Number	Place	Year	Sowing dates				S.E.	Significance
			SOUTH EAST THARPARKAR					
			(Recommended optimum sowing period 25 April to 10 May)					
1	Deinsar Estate	1943	23 March 14·9	6 April 16·3	20 April 15·6	4 May 13·9	±0·76	Non-significant.
2	do.	1943	2 April 18·86	23 April 18·96	16 May 18·85	3 June 16·51	±0·878	Non-significant
3	do.	1944	25 March 6·99	15 April 10·20	4 May 9·44	24 May 7·95	±0·406	1 per cent
4	do.	1944	..	22 April 10·88	..	23 May 9·58	±0·502	Non-significant
5	do.	1945	6 April 13·3	25 April 15·0	15 May 11·7	6 June 6·2	±0·93	1 per cent
6	do.	1946	1 April 12·1	15 April 11·6	30 April 12·8	15 May 13·5	±0·636	Non-significant
7	Kinjhejhi	1943	29 March 13·02	19 April *17·41*	9 May *17·44*	30 May *18·51*	+0·927	1 per cent
8	do.	1944	8 April 18·13	6 April 18·21	15 May 19·86	3 June 15·97	±0·84	5 per cent
			NORTH EAST THARPARKAR					
			(Recommended optimum sowing period 1 April to 15 May)					
12	Mirpurkhas	1943	9 April 10·50	30 April 13·39	20 May 17·56	10 June 13·76	±0·525	1 per cent
13	do.	1943	13 April 7·85	4 May 6·89	24 May 7·38			
14	do.	1945	2 May 17·0	18 May 15·8	31 May 12·4	14 June 8·0	±1·19	1 per cent
15	do.	1946	8 April 13·9	23 April 14·3	8 May 14·8	25 May 14·7	±0·88	Non-significant
17	Tando Jam	1946	22 April 18·1	5 May 13·5	20 May 18·5	2 June 12·4	±1·65	5 per cent

TABLE IV—*contd.*

Mean yield in maunds per acre under different sowing dates in Sind (1943-46)—contd.

Experiment Number	Place	Year	Sowing dates				S.E.	Significance
			HYDERABAD					
			(Recommended optimum sowing period 15 April to 30 May)					
18	Hyderabad	1944	22 April 13·89		23 May 15·93		±0·594	5 per cent
19	do.	1944	17 April 21·51	5 May 17·07	3 June 15·05	24 June 15·29	±1·15	1 per cent
20	do.	1945	30 April 18·6	21 May 19·2	11 June 20·1		±1·09	Non-significant
21	do.	1946	15 April 16·9	30 April 14·8	15 May 12·1	30 May 12·8	±1·18	5 per cent
22	Oderolal	1945	5 May 20·5	17 May 21·2	2 June 18·4	16 June 17·5	±1·76	Non-significant
23	do.	1946	19 April 16·1	4 May 11·7	19 May 11·1	3 June 14·1	±0·99	5 per cent
			MIDDLE SIND					
			(Recommended optimum sowing period 20 May to 30 June)					
24	Sakrand	1943	14 May 11·44	3 June 11·10	24 June 12·72	17 July 12·42	±0·99	Non-significant
25	Sakrand A.R.S.	1943	22 May 15·77	10 June 15·99	3 July 14·34	22 July 17·07		
26	do.	1944	25 May 16·15		25 June 14·33		±0·587	5 per cent
27	do.	1944	25 May 14·43		25 June 10·56		±0·911	5 per cent
28	do.	1945	20 May 13·4	9 June 11·4	29 June 11·5		±0·96	Non-significant
29	do.	1946	18 May 9·9	3 June 12·7	22 June 11·5	8 July 9·3	±0·92	Non-significant
31	Nawabshah	1946	10 May 20·0	25 May 18·6	20 June 18·1	26 June 21·0	±1·08	Non-significant
33	Pad Idan Farm	1946	22 May 10·3	7 June 11·2	22 June 9·6	7 July 11·0	±0·55	Non-significant
			NORTH SIND					
35	Dokri A.R.S.	1943	21 May 6·66	12 June 10·89	1 July 10·00	21 July 5·90	±1·246	5 per cent
36	do.	1943	6 June 7·43	27 June 9·72	10 July 8·80	28 July 5·66	±0·896	5 per cent
37	do.	1945	7·7	9·2	7·6	9·45	±0·940	Non-significant

The main effects of dates came out to be highly significant at one per cent level in eight experiments (Nos. 3, 5, 7, 10, 11, 12, 14 and 19) and at five per cent level in nine experiments (Nos. 8, 17, 18, 21, 23, 26, 27, 35 and 36). In the remaining 14 experiments the dates were not significant.

There were also other environmental and local factors that were also considered in fixing the sowing periods a little earlier than what were warranted by the results of the experiments. They are briefly mentioned below.

The climatic conditions in the Tharparkar and Hyderabad tracts (South and East Sind) at the fruiting stage were such that there was no possibility of an increase in the intensification and the spread of *tirak* and causing cotton failures as had been the case in the Punjab. In this major American cotton growing tract the 'bad opening' of bolls would be only confined to highly saline lands. It was not, therefore, necessary to delay the sowings too long in this tract as that would entail the following disadvantages.

There was also an earlier onset of reproductive phase in the month of July in this tract as compared with other tracts where the reproductive phase set in in the month of August. It was, therefore, necessary to plant the crop sufficiently early to enable it to produce adequate vegetative structure before fruiting began; otherwise there would be a great reduction in bearing points per acre which cannot be made up by even adopting closer spacing.

It was also not practical to delay sowings which would necessitate the adoption of closer spacing than of 2 ft. between rows as the cultivators may not drill cotton seeds at a closer distance than 2 ft. in order to keep adequate space between the rows for interculture. It may be stated here that the major part of the cotton in Sind was at present broadcast and not drilled and in order to give effect to these recommendations, cotton will have to be sown in lines.

The danger of damage caused by Jassids especially to late sown crop was always there as both the Sind-American varieties, M4 and Sind Sudhar, especially the latter were susceptible to this insect pest.

It was also necessary to safeguard against delays in sowing caused by unforeseen factors such as canal closure, untimely showers of rain, etc. and this can be avoided by starting sowings earlier than the date arrived at from the results of the experiments. The Department of Agriculture, Sind, has recommended, as stated before a sowing period of 30 days for each tract. In view of what is stated above it was considered advisable to fix a 40 to 45 days sowing period so that sowings can be completed in time in spite of unforeseen difficulties. If, however, a cultivator can manage to sow all his cottons in a shorter, period than the one recommended below he can start his sowings with advantage ten to fifteen days later than the dates indicated below.

It was found by experience advantageous to sow all unfertile or poor lands in the first half of the sowing period recommended as later sowings have been found to make very poor growth and were found to be very liable to Jassid damage.

As all the experiments arranged in North Sind (with the exception of Nos. 35 and 36 of 1943) were spoiled either on account of root rot, white ants or frost, no recommendations for the optimum sowing period for cotton in that tract could be made. It may be stated here that the acreage under Americans in North Sind was very small and negligible and the sowing period in North Sind was found more or less to correspond with the sowing time in Middle Sind.

The following Table V gives the recommended sowing periods for cotton in the different tracts after taking into consideration the results of all the experiments and the various points discussed above.

TABLE V

Optimum sowing time for American cotton in different tracts of Sind

Tract	Sowing period	Spacing in First fortnight of the sowing period	Second fortnight of the sowing period	Third fortnight of the sowing period
South East Tharparkar	1 April to 15 May	3 ft. × 1½ ft.	2½ ft. × 1 ft.	2 ft. × 1 ft.
North East Tharparkar	10 April to 25 May	do.	do.	do.
Hyderabad Tract	15 April to 30 May	do.	do.	do.
Middle Sind	20 May to 30 June	do.	do.	do.

As the number of cotton rows would increase as the spacing between the rows was reduced from 3 ft. to 2 ft., it would be necessary to increase proportionately the seed rate per acre in order to get the required stand. The standard seed rate recommended by the Department of Agriculture for cottons sown at 3 ft. distance was 24 lb. per acre. So the seed rate will have to be increased to 28 lb. and 32 lb. per acre for the cotton sowings in the second and the third fortnight of each sowing period. In the experiments conducted in Sind slightly higher seed rates than those given above were used to ensure the spacings required to be kept.

The Sind American strain M4 gave higher yields per acre varying from 1½ maunds to 5 maunds (Table I) than the other strain Sind Sudhar in 27 experiments out of a total of 37 experiments in which two varieties were included. In the remaining experiments the yields of the two varieties were nearly equal. This difference in the

yielding capacities of the two varieties was greater in the South and East Sind than in the Middle Sind where Sind Sudhar gave as high yields as M4. This may have some relation to the places where these strains were evolved. M4 was evolved in south Sind while Sind Sudhar was evolved in Middle Sind.

Another noticeable feature of M4 was its greater suitability for late sowing than Sind Sudhar. The sowings of M4 could, therefore, be delayed without reducing the yields for a longer period than the other variety.

CONCLUSIONS

Though 'bad opening' of bolls as measured by the boll weight method was found to decrease progressively as the sowing date advanced, there were no corresponding increases in yields as the sowing date advanced even in combination with close spacing in some of these 38 experiments conducted in the different tracts. The yield under the last sowing date was in some cases lower than that in the first or second sowing dates. The last sowing date up to which cotton could be profitably sown, therefore, varied in different experiments conducted in a tract. It was, therefore, not possible to recommend very late sowing even in combination with close spacing though 'bad opening' of bolls was remedied by delaying sowings. Early sowings affected adversely the boll weight while late sowings adversely affected the boll number. Very early and very late sowings had, therefore, to be avoided.

It was also necessary to recommend a long sowing period of 45 days in order to enable a cultivator to complete all his cotton sowings before the last sowing date and allowance had to be made for any interruption in his cotton sowing programme on account of dust storm, light showers of rain, canal closure and other uncontrollable factors.

On account of the reasons mentioned above the sowing periods recommended for each tract did not differ to a great extent from the cotton sowing time recommended by the Agricultural Department. The main difference was that a sowing period of 45 days instead of 30 days was recommended and last sowing date was extended on account of the adoption of close spacing.

The cotton crop in Sind was being sown at a distance of 3 ft. between rows and thinned to $1\frac{1}{2}$ ft. between plants irrespective of sowing date. It appeared from the experiments conducted here that it would mean some loss in yield on majority of fields in the crops sown in the latter half of the sowing period. Though the results obtained in the sowing date-cum-spacing experiments varied greatly, it was clear that adoption of closer spacing had increased in many cases the yield per acre in the late sown crops. In no case a decrease in yield was registered in the late sown crop which was closely spaced.

SUMMARY

As late sowing was found to lessen damage caused by 'bad opening' of bolls on the two soil types, (i) light sandy and (ii) soils with saline subsoils, it was undertaken to determine how far the sowings of cotton can be delayed in order to minimize

the loss caused by 'bad opening' of bolls. At the same time, it was necessary to avoid the loss in yield caused by a decrease in bearing in the late sown crop even though it may be closely spaced. It was also necessary to know to what extent the measure of close spacing can be profitably practised and to establish the spacing to be adopted with each advancing fortnight in the sowing date.

As the sowing period was found to vary in the different cotton tracts, the optimum sowing period covering a range of 45 days in each tract was determined.

The behaviour of the two Sind-American varieties and one Punjab-American variety in different tracts was also determined.

In all 38 factorial experiments were laid out in the Tharparkar and Hyderabad tracts in South and East Sind and in Nawabshah tract of Middle Sind. As a result of these experiments, optimum sowing time as determined by the magnitude of the yields under three or four sowing dates in the experiments conducted in each tract was fixed. It is recommended to reduce the spacing between rows from 3 ft. to $2\frac{1}{2}$ ft. and subsequently to 2 ft. for each advancing fortnight in the 45 days sowing period.

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COLOURS OF SOILS OF MADHYA PRADESH

ROLE OF MECHANICAL FRACTIONS AND ORGANIC MATTER IN COLOUR FORMATION

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(With Plates XXXI to XXXV)

THE subject of colours of soils has attracted the attention of good many workers in the past, Much of the information we have on the subject is, however, contained in works dealing with other problems, very few of which have a direct bearing on the soil colour study.

A major portion of the work, pertaining to this problem, is on the relation of the chemical characters to soil colour. Of these, the presence of organic matter in its various forms in the soil and its effect on soil colour formation have been the theme of workers up to the present. The other important constituent that has been known to impart colour to a soil is iron, in the form of its hydrated and dehydrated oxides and in combinations, such as titaniferous magnetite, iron silicates, etc.

It has been pointed out by Annet [1906], Danial (1938) Vlasoff and Whittling (1937), Raychaudhuri [1939] and others that the black soil contains a high percentage of clay. But no worker seems to have as yet tried to show the specific role of clay or its contents in imparting colour to a soil. Nor has any attempt been made to find out how far the other mechanical fractions contribute in imparting colour to a soil.

A survey of literature reveals that workers have generally tried to understand black and red soil colours as having been caused by the presence of certain particular constituents. It has not been clearly recognized in these investigations that a combination of different influences might be responsible for what we may call the composite colour of a soil. No attempt has been made to show to what extent a particular constituent of a soil is responsible for a particular colour component and how far the removal of this particular constituent of the soil affects the colour of the residue.

The present paper is an outcome of a study of the subject from the aspects mentioned above.

Experimental

Collection of material

As it is observed that the soils are characterized by the colour of their surface layers and not by the colour of their entire profile, the soils used under the investigation are, samples of surface soils, only up to a depth of 9 in., passed through a 2 mm. sieve. About three to four samples of typical soils of Madhya Pradesh representing each colour group, *viz.*, the black, the red, and the yellow were collected and employed for the purpose of this investigation. The soils are derived from a variety of rock systems and occur under only slightly varying climatic conditions. The percentages given in the various analytical tables are on air dry basis.

Table I gives a short general information regarding the samples used :

TABLE I

Soil samples and their characteristics

Serial number	Name of soil	Colour	Locality	Origin
		Black soils		
1	Black cotton	Black	Nagpur	Trap rock.
2	Kabar	Do.	Patni village, Hoshangabad district.	Uncertain origin, probably a mix-up of trap and limestone.
3	Kheri	Do.	Kheri Farm, Jubbulpore district.	Do.
4	Kanhar	Do.	Labhandi, Raipur District	Mixed limestone and sandstone.
5	Mariar	Ashy black	Hoshangabad District	Alluvium from trap and mixed sandstone limestone region
		Red soils		
6	Hill top	Dark red	Nagpur	Trap rock.
7	Wardi	Light red	Sindewahi farm, Chanda District.	Mixed sandstone.
8	Bhata	Red	Chandkhuri Farm, Chanda District also present in Labhandi, Raipur District.	Mixture of limestone and sandstone.
		Yellow soils		
9	Dorsa	Blackish yellow	Labhandi, Raipur District.	Mixture of limestone and sandstone.
10	Sehar	Light yellow	Waraseoni, Balaghat District.	Sandstone.
11	Matasi	Bright brownish yellow.	Labhandi, Raipur District.	Limestone and sandstone.

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Colour records of soils under investigations

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It is generally observed that the red soils are situated at the higher level whereas the black soils are at the lowest level, soils of intermediate colours lying in between these two types. For example hill top soil Nagpur (No. 6) is at the top of the hill, whereas the Black cotton soil is at the base of the hill in a basinlike formation. Similarly Bhata soil (No. 8) is at the highest elevation, followed by Dorsa (No. 9) and Matasi (No. 11) whereas the Kanhar soil (No. 4) lies at the lowest level.

The technique used in recording of colours of soils on various treatments, was based on the same principle as used by Whittles [1931]. Plate XXXI shows the colours of soils used.

Soil colour in relation to the mechanical composition and the mechanical fractions of the soil

A review of literature reveals that of all the physical characters of the soil, the mechanical composition of the soil has received more attention. As already pointed out a number of workers have shown that black colour is always associated with a high percentage of clay in a soil. The determinations of the mechanical composition of soils under investigation done by the Robinson's modification of the International method, show that although there is no steadfast correlation of the texture of the red and the yellow soils with their colour, the black soils contain on an average a much higher percentage of clay than these soils.

TABLE II

Mechanical composition of the soils

Serial number	Soil	Clay per cent	Silt per cent	Fine sand per cent	Coarse sand per cent
	Black soils				
1	Black cotton, Nagpur	56·3	20·2	11·50	4·63
2	Black cotton, Akola	50·11	16·01	12·99	7·02
3	Kabar	64·70	17·91	10·55	4·72
4	Kanhar	55·90	21·93	13·23	3·22
5	Kheri	54·10	19·50	17·29	3·61
6	Mariar	31·60	36·00	18·53	2·03
	Red soils				
7	Top Telankheri, Nagpur	42·40	21·95	13·60	10·92
8	Wardi	23·45	11·40	44·14	18·52
9	Bhata	14·93	14·40	17·67	51·76
	Yellow soils				
10	Dorsa	42·47	28·75	17·40	5·90
11	Sehar	24·55	25·00	34·55	9·77
12	Matasi	24·80	36·80	35·19	1·49

Although it is apparent from the above considerations that black colour is always associated with a high percentage of clay, the actual part played by clay or the other fractions of the soil in imparting colour, has not been investigated. Moreover, it is well known that the soil properties due to clay are modified by the presence of other fractions, particularly the silt. It, therefore, seems as much necessary to determine the part played by these fractions in soil colour formation. With this view, the mechanical fractions of the soils under investigation were collected according to the method used in the mechanical analysis, but without giving any drastic pretreatment. The colours of these various fractions were recorded and are shown in Plates XXXII and XXXIII.

It is clearly seen from these Plates that the clays of all soils have more or less the same colour as their corresponding soils. The colours of the silt fractions are altogether different from those of the corresponding clay fractions of the respective soils. The fine sand fractions resemble their corresponding silt fractions but are more brownish. The coarse sand fraction often contains particles of undecomposed rock materials, particles of precipitated iron oxide and other coarser materials like undecomposed organic residues, etc. It is, thus, not possible to interpret the colours of this fraction as it contains materials which are likely to vary from sample to sample.

Black soils. In the case of black soils the clay forms on an average more than 50 per cent of the soil material and is deep black in colour. The other important fraction in these soils, i.e., the silt is ashy or ashy-brown in colour and only tones down the colour of the soil due to clay. The fine sand and the coarse sand fractions do not appreciably affect the soil colour except giving it a slight brownish tinge, as their percentages are comparatively small.

Red soils. In the case of hill top soil, Nagpur, the colour of the clay is red, whereas the colours of the other fractions are dark gray or brown. As this soil contains a fair proportion of the coarser fractions, the colour of the soil becomes grayish red. The Bhata soil contains nearly 50 per cent of coarse sand and the remaining is made up equally of the other fractions. The colour of the soil is, therefore, due to the colour of the coarse sand fractions and is only modified by the colours of the other fractions in the soil. The same is the case with the Wardi soil, whose colour is also mainly due to coarse sand.

Yellow soils. The colours of the yellow soils are essentially due to the colours of the clay fractions and are modified to a certain extent by the colour of the other fractions.

It is, thus, clear from the above findings that whereas the colours of the black and the yellow soils are essentially due to the clay fraction, the colours of the red soils, is due to the coarse fractions.

Effect of organic matter on soil colour

The colour of a soil has mainly been attributed to two chemical factors, namely, the organic matter and the mineral matter of the soil. Considering the organic

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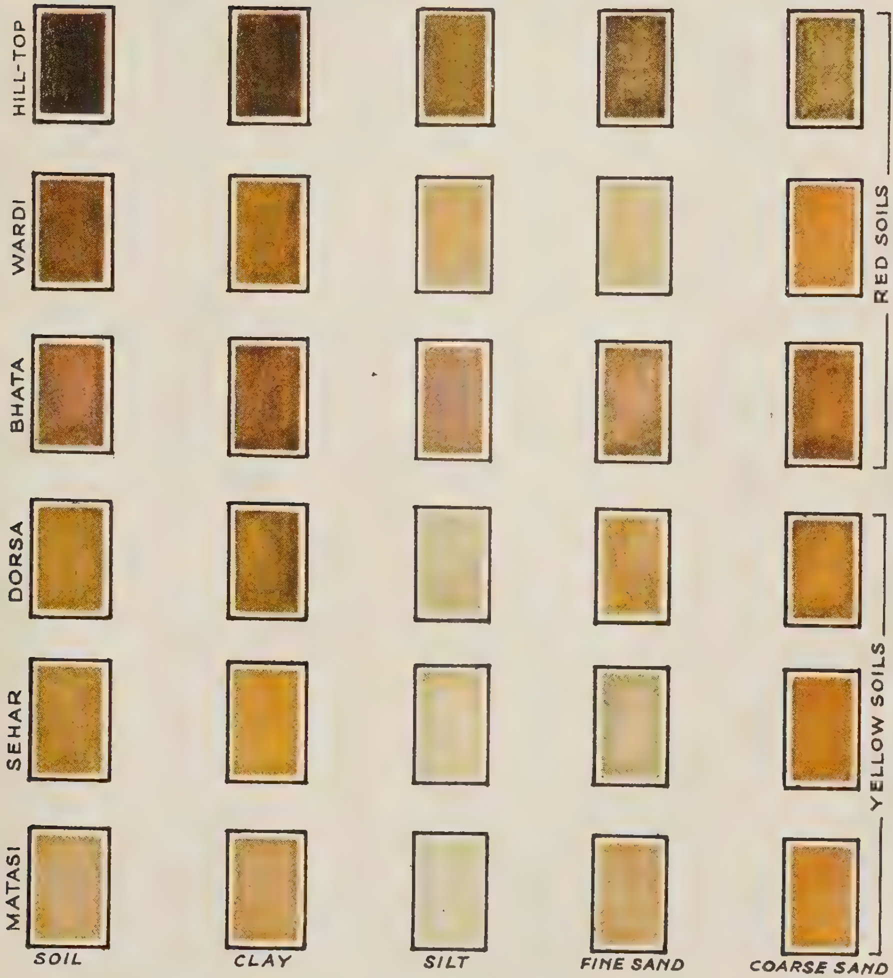

Mechanical fractions of soils under investigations
(Red soils and yellow soils)

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Mechanical fractions of soils under investigation
(Black soil)

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matter alone, it has been the view of earlier workers like Alway [1916] and Glinka that a black or a gray colour is associated with a high content of organic matter. More recently Utesher [1932], Danial [1938], Schefer [1943] and others have begun to find that it is not the amount but the nature of the organic matter that is responsible for the presence of a black or gray colour in a soil. Some feel that it is the organic matter in a highly humified form that is responsible for the darkness of colour in a soil, whereas Tang [1935], Raychaudhuri [1939] and others have tried to correlate soil colour with the C/N ratio. Desai [1942] points out that two factors may be the cause of dark colour (No. 1). Humus in fully saturated condition has been shown by various workers to be very dark in colour; (No. 2) since the soils are very wet, the iron which is largely in the finer fractions is in a reduced condition and thus added to the dark colour of the humus. Recently, Plice [1944] and Ramiah and Raghavendrachar [1936], have pointed out that it is the mineral matter in combination with the organic matter, that is responsible for the variations of colour in a soil. It is, therefore, proposed to study soil colour from some of the aspects as mentioned above.

Soil colour and the organic matter content

The organic matter of the soils under investigation was determined by Allison's [1935] method, whereas the nitrogen was determined by Bal's (1925) modification of the Kjeldahl's method. Table III gives the figures of analysis.

TABLE III

Showing the percentage of C, N and the organic matter of the soils

Serial number	Soil	Carbon per cent	Nitrogen per cent	Organic matter per cent
	Black soils			
1	Black cotton, Nagpur	0·632	0·0549	1·087
2	Kabar	0·370	0·0483	0·610
3	Kheri	0·464	0·0406	0·799
4	Kanhar	0·460	0·0440	0·793
5	Mariar	0·489	0·0438	0·843
	Red soils			
6	Hill top, Nagpur	0·568	0·0905	0·976
7	Wardi	1·16	0·107	2·003
8	Bhata	0·598	0·0594	1·020
	Yellow soils			
9	Dorsa	0·789	0·0689	1·35
10	Sehar	0·725	0·0602	1·25
11	Matasi	0·696	0·0608	1·22

Considering soil colour from the point of view of the organic matter content, it has been the view of workers that the more the amount of organic matter in soil the more darker it is in colour. Waksman [1936] has shown that the percentages of humus in black soils (Chernosems) are higher than the gray (Serosems), the brown (Chest-nut), or red (Krasmosems). It will be seen from Table III that the soils under investigation are on average poor in their organic matter content. The organic matter content of the black soils in particular is small as compared with that of soils whose black colour is attributed to their (*e. g.* Chernosems) richness in organic matter. It is also seen from Table III that the black soils contain on average a lower percentage of organic matter as compared with soils of other colours.

It is, thus, evident that the amount of organic matter is not responsible for the colour variations of the soils under investigation.

Soil colour in relation to the organic matter in the mechanical fractions

With a view to finding out whether the organic matter of the soil is fixed mostly in any particular mechanical fraction in soils of a specific colour, the mechanical fractions were collected separately by the same method as used for the mechanical analysis of soils and their organic matter determined. Although, as will be seen later, this method removes a part of the organic matter by treatment with H_2O_2, the analysis of the residual organic matter can give an idea of the resistant (to H_2O_2) organic matter in each of the mechanical fractions of the soils. Table IV gives the percentages of organic matter in mechanical fractions of the soils under investigation, whereas Table V gives the percentage distribution of the organic matter in the various mechanical fractions. The strikingly high percentage distribution of organic matter in the coarse sand of the Bhata soil is due to its containing a high percentage of coarse sand.

TABLE IV

Percentages of organic matter in the mechanical fractions of the soils under investigation

Serial number	Soils	In soils after H_2O_3 treatment	In clay	In silt	In fine sand	In coarse sand
			Black soils			
1	Black cotton, Nagpur	0·997	0·642	1·22	0·481	0·290
2	Kabar	0·328	0·262	0·398	0·392	0·325
3	Kheri	0·504	0·397	0·353	0·042	..
4	Kanhar	0·715	0·540	0·650	0·210	0·123
5	Mariar	0·727	0·631	1·353	0·247	0·902

TABLE IV—*contd.*

Percentages of organic matter in the mechanical fractions of the soils under investigation—contd.

Serial number	Soils	In Soils after H_2O_2 treatment	In clay	In silt	In fine sand	In coarse sand
			Red soils			
6	Hill top, Nagpur	0·821	0·746	1·15	0·898	..
7	Wardi	0·504	0·957	1·50	0·123	0·037
8	Bhata	0·985	2·27	0·969	0·530	0·561
			Yellow soils			
9	Dorsa	0·561	1·12	0·310	0·529	0·325
10	Sehar	0·234	0·890	0·129	0·138	0·020
11	Matasi	0·399	0·895	0·202	0·160	0·062

TABLE V

Percentage distribution of organic matter in the various mechanical fractions of the soils used

Serial number	Soils	In clay	In silt	In fine sand	In coarse sand	Difference due to loss by the action of N/5 Hcl, H_2O_2, and ammonia during fractionation
			Black soils			
1	Black cotton, Nagpur	36·26	29·44	5·55	1·35	32·40
2	Kabar	51·68	21·72	9·39	4·63	12·58
3	Kheri	42·62	13·66	1·46	..	42·26
4	Kanhar	38·96	18·40	3·58	..	48·16
5	Mariar	27·43	67·45	6·30	2·53	..
			Red soils			
6	Hill top, Nagpur	38.43	30·75	14·82	..	16·00
7	Wardi	44·52	25·47	10·74	1·36	19·91
8	Bhata	34·41	14·17	9·51	29·49	12·42
			Yellow soils			
9	Dorsa	84·63	15·85	16·50	3·90	..
10	Sehar	93·30	13·76	20·51	..	..
11	Matasi	55·62	14·63	14·11	..	15·64

It will be observed from these tables that the clays of black soils contain a distinctly lower percentage of organic matter than the clays of soils of other colours. It is also observed that the soils of black colour lose more amount of organic matter by the treatment of reagents during mechanical analysis, than soils of any other colour. Even in spite of such loss these soils retain their colour. It, thus, appears probable that this organic matter present in these soils, and particularly in their clays must be characteristically different than the organic matter of the soils of other colours.

Soil colour and C/N ratio

It has been already pointed out that the C/N ratio, being indicative of the nature of organic matter, has been correlated with the colour of a soil. With this view, the C/N ratios of the soils under investigation and their clays were determined and Table VI gives the results of analysis.

TABLE VI

C/N ratios in clays and soils

Serial number	Soils	C/N ratio in clays	C/N ratio in soils
	Black soils		
1	Black cotton, Nagpur	6·86	11·50
2	Kheri	4·28	11·43
3	Kanhar	7·30	10·27
4	Mariar	6·80	11·26
	Red soils		
5	Hill top, Nagpur	8·02	6·28
6	Wardi	7·23	10·8
7	Bhata	10·20	10·07
	Yellow soils		
8	Dorsa	12·60	11·40
9	Sehar	11·86	12·02
10	Matasi	7·68	11·44

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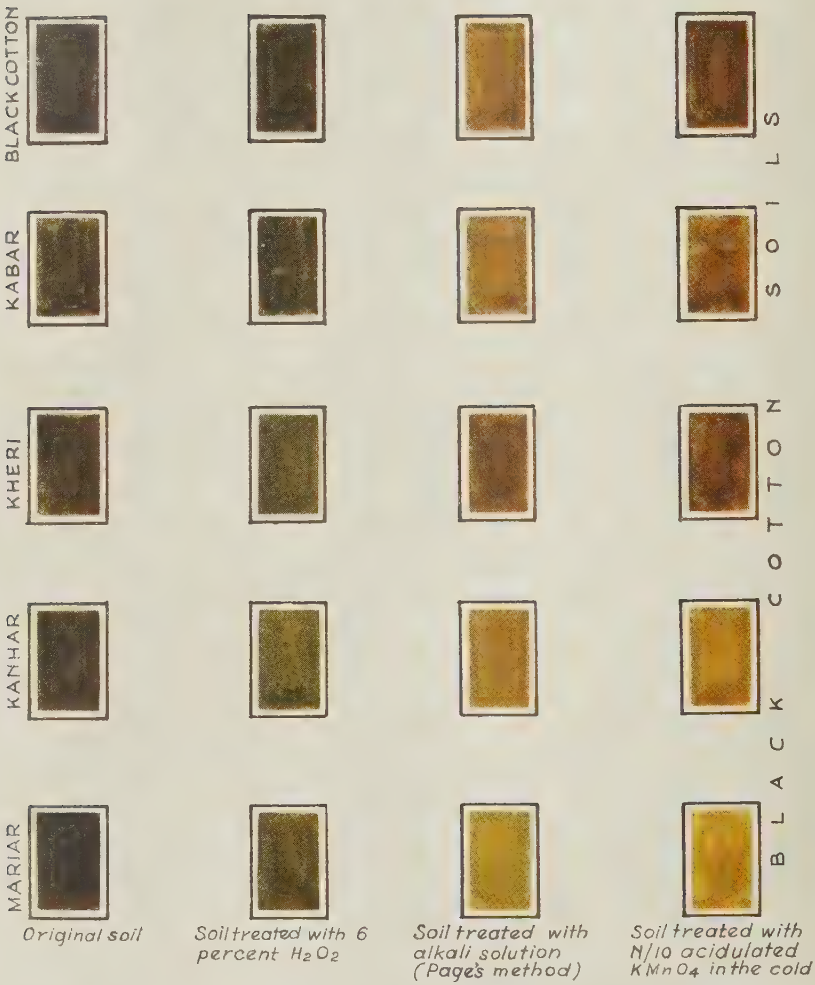


The action of organic matter solvents on the colour of black soils.

It is seen from Table VI that the C/N ratio of the soils is fairly constant, *i.e.* within the limits of 10 to 12. The C/N ratios, as will be seen from column 2 of Table VI of the clays of black soils are distinctly lower than the ratios of the clays of soils of other colours.

Effect of some organic matter solvents on soil colour

To study further the nature of organic matter in relation to soil colour, the soils under investigation were treated with N/5 HCl, H_2O_2 (6 per cent) preceded by N/5 HCl, alkali solution, and acidulated potassium permanganate (N/10 roughly) respectively and the colours of the residual soils were recorded (Plate XXXIV). The method of treatment with alkali solution was based on the method by Page [1930]. Table VII gives the figures of analysis as obtained by the above treatments.

TABLE VII

Percentages of organic matter decomposed by the action of reagents

Serial number	Soils	Per cent organic matter					
		In original soil	Inresidual soil on H_2O_2 treatment	Extracted from the soil by H_2O_2	On treatment with N/5 HCl	Removed from soil on alkali treatment (Pages method)	Extracted from soil by alkali
	Black soils						
1	Black cotton, Nagpur	1·087	0·997	7·7	0·017	0·844	77·6
2	Kabar	0·607	0·328	25·4	0·070	0·516	38·5
3	Kheri	0·758	0·504	33·5	0·14	0·566	74·7
4	Kanhar	0·793	0·715	9·8	0·003	0·463	58·4
5	Mariar	0·820	0·727	11·2	..	0·552	67·3
	Red soils						
6	Hill top, Nagpur	1·100	0·821	25·4	0·017	0·650	59·1
7	Wardi	2·002	0·504	70·6	0·270	1·300	64·3
8	Bhata	1·03	0·985	4·2	0·460	0·618	60·0
	Yellow soils						
9	Dorsa . .	1·12	0·561	54·6	0·151	1·12	100·0
10	Sehar . .	1·20	0·234	80·5	0·206	0·673	56·1
11	Matasi . .	1·26	0·399	67·3	..	0·938	74·4

Table VII clearly shows that the organic matter lost by treatment with N/5 HCl is negligible in all cases.

Regarding the action of H_2O_2 on soils, although the action of the reagent is not quite uniform, it is seen that the black soils, on average, are more resistant to this reagent than the soils of other colour. This observation is contrary to that of Hosking [1911] who finds that the black soils turn light gray or brown by this action. It is also observed in the case of this reagent that the black soils do not lose their colour even on repeated treatment.

It will be seen from Table VII that the soils under investigation lose on average 70 per cent of the organic matter on treatment with alkali solution. It is, however, found that whereas the red and the yellow soils do not lose their colour by this treatment, the black soils are changed to either light gray or brown. The clays of black soils have been observed to lose all their organic matter and turn dark brown in colour.

To ascertain, further, whether the loss of colour by the black soils, with the action of this reagent, was due to the difference of colour of the humus extracted from these soils and that extracted from soils of other colours, the humus in alkali solutions of all soils was precipitated with an acid. The humus preparations thus obtained from the various soils under investigation were all identical in colour both in the solid state and in solution. This observation is also contrary to that of Alway and Blish [1916] who find that the humus from soils possess colour varying from dark brown to deep black.

A dilute solution (N/10) of potassium permanganate previously acidified with a dilute solution of sulphuric acid has been found to exert a very rapid decolourizing effect on the black soils even in the cold condition. The soils are found to lose their colour and more or less all their organic matter by this treatment. This procedure is, therefore, adopted to obtain soils free from organic matter.

The red and the yellow soils do not show any change in colour by the action of the reagents mentioned above.

It is, thus, seen from the above observations that, it is the organic matter, soluble in either the alkali solution or the solution of potassium permanganate that is responsible for the black colour of the soils under investigation.

Fractionation of organic matter and soil colour

To study further the relationship of colour with the nature of organic matter, the fractionation of the organic matter of the soils under investigation was done according to Waksman's technique. The results of analysis are given in Tables VIIIA and Table VIIIB. It is seen from these lables that the organic matter of these soils is essentially made up of the lignin-protein fraction. These soils show a general resemblance in the composition of their organic matter to those as given by Waksman. The soils, however, do not show any relationship of their colour with the organic matter fractions.

It, therefore, appears that the lignin-protein matter, which is the main constituent of the organic matter of the soils under investigation, is tied up with the mineral clay to form a black clay-humus-complex, only under suitable conditions as will be discussed presently.

TABLE VIIIA

Proximate chemical composition of organic matter of soils under investigation, on the basis of total organic matter (CXI·724)

Serial number	Soil	Ether and alcohol soluble extract	Hemi-cellulose	Cellulose	Lignin	Protein
			Black soils			
1	Black cotton, Nagpur	2·03	2·10	4·10	53·3	38·9
2	Kabar	0·46	2·28	9·00	32·4	51·1
3	Kheri	0·50	1·35	8·90	53·3	32·7
4	Kanhar	*nil*	2·55	5·1	54·1	43·5
5	Mariar .	2·04	3·40	3·6	51·1	45·2
			Red soils			
6	Hill top, Nagpur	2·15	2·80	4·1	57·5	38·3
7	Wardi	4·48	13·40	8·0	52·1	39·7
8	Bhata	3·41	6·21	7·4	53·6	32·1
			Yellow soils			
9	Dorsa	8·60	3·03	11·3	45·8	34·8
10	Sehar	3·80	4·20	7·0	26·3	36·4
11	Matasi	2·10	4·30	4·7	28·4	32·7

TABLE VIIIB

Composition of organic matter for some typical soils, calculated on basis of soil organic matter (CXI·72) (Waksman and Stevens)

Serial number	Soil	Ether soluble	Alcohol soluble	Hemi-cellulose	Cellulose	Lignin humus complex	Proteins
1	Summit soil-organic matter 4·49 per cent	3·56	0·58	5·44	3·55	43·57	33·78
2	Kansas Tshernosem—Organic matter 5·98 per cent	4·71	1·53	8·60	5·22	40·81	34·74
3	Alberts Tshernosem Organic matter 11·20 per cent	0·80	0·82	5·53	4·12	41·87	37·35
4	Carrington loam—organic matter 6·48 per cent	0·62	0·62	8·21	3·64	42·29	30·38

The roll of clay-humus-complex in soil colour formation

The combination of humus with the inorganic soil colloid or the mineral clay to form a clay-humus-complex is now universally recognized. The conditions under which it is formed have also been studied by various workers. This clay-humus-complex is considered to be endowed with physico-chemical properties such as the base exchange, etc. On this basis and on the basis of certain observations Ramiah and Raghavendrachar [1936] have recently suggested that it is the organic matter, in association with clay and with a high SiO_2/Al_2O_3 ratio and also high in CaO-MgO, which is responsible for the black colour of soils. No direct experimental evidence has been set forth as yet in support of this view. It is, therefore, proposed to consider the possibility of such a view in the light of the observations made.

The black soils contain on an average 20 to 30 per cent more clay than the soils of other colours. It is, moreover, observed that it is these clay fractions that are responsible for the presence of the colour in the black soils.

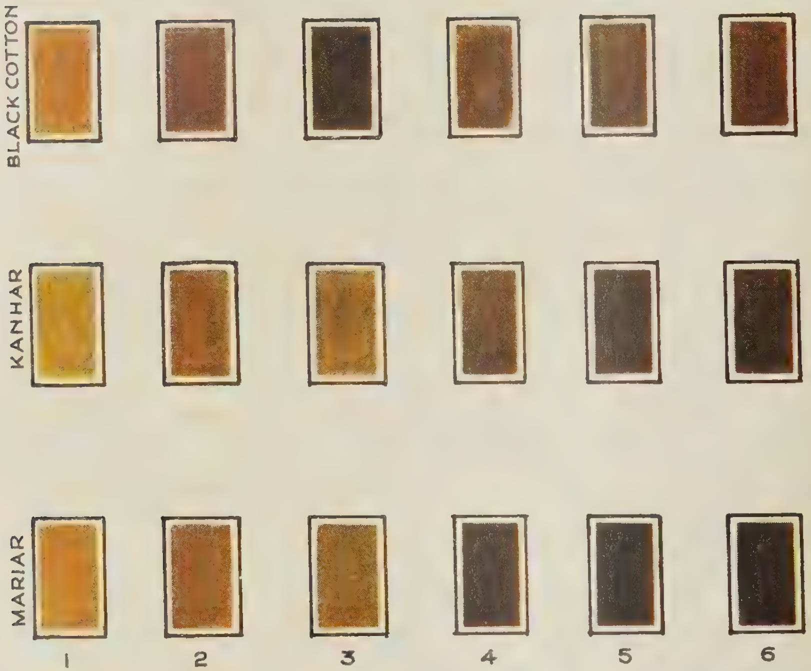
It has also been shown that the black colour of the soils cannot be due to the amount of humus or its colour. It is, however, found that the removal of this humus from the black soils also removes their black colour. This observation has also been found to hold true in the case of the clays of these black soils. Considering these two observations, it appears that it must be the nature of combination of this humus that must be different in the case of black soils. This has been indicated by the fact that the humus in these cases is very resistant to the action of reagents and that the clays of these soils have narrower C/N ratio than the clays of soils of other colours.

It will, thus, be clear from the above considerations that the humus must be in combination with the mineral clay to form the clay-humus-complex, and it is thus that this complex must be giving the black colour to soils. This colouring component as already pointed out is absent in the soils of other colours, unless they are of a mixed character (the hill top soil, Nagpur and the Dorsa soil).

To study further the exact conditions under which the humus combines with mineral matter of the soil to give black colour, the following colour fixation experiments were conducted.

(1) Five grams of mineral matter (colour-brown) of a black cotton soil was treated with a slightly alkaline solution of humus also extracted from the same Black cotton soil. The solution added was 150 c.c., containing about 0·1 to 0·2 gm. of humus in solution. It will, thus, be seen that the soluble humic acid in contact with the mineral matter was more than double than what is present normally in these soils.

(2) Five grams of the same mineral matter were treated with 150 c.c. of a neutral solution of ammonium humate prepared from the same Black cotton soil. The amount of humus in solution was the same as in above.



TREATMENTS—

1. Original decolourised soil.
2. Soil obtained by treating (1) with humus in neutral solution.
3. Soil obtained as in case (2) but under slightly alkaline conditions.
4. Soil obtained as in case (2) but previously saturated with calcium.
5. Soil obtained as in case (2) but previously saturated with magnesium.
6. Soil obtained as in case (2) but in presence of 4% $Ca\ Co_3$

Refixation of Black colour in the decolourised black soils by solution of humus under various conditions.

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(3) Five grams of a mineral calcium soil prepared from the same original material was treated with 150 c.c. neutral solution of ammonium humate as in Experiment 2 above.

(4) Experiment 3 was repeated by using a magnesium instead of a calcium soil.

(5) Five grams of a mineral hydrogen soil was treated with 150 c.c. of a neutral ammonium humate solution as in Experiment 2 but to which 0·2 gm. of calcium carbonate was also added.

The above mineral materials were shaken up with their respective solutions, exposed to sunlight from time to time and allowed to remain in this condition for a fortnight. After this period the materials were washed free of the soluble matter and dried. Plate XXXV shows the colours of the products obtained.

In treatment 1, there was no rapid precipitation of humus but the original brown colour of the mineral matter changed to black within about a week. The black colour was, however, tinged with the brown colour due to humus.

In treatment 2, there was a rapid precipitation of humus and the colour of the residual matter was dark brown.

In treatment 3, the loss of the humus from solution was also rapid but slower than in case of treatment 2. The colour of the residue was distinctly black but slightly tinged brown.

In treatment 4, the precipitation of humus was slow and the colour of the residue was brown, tinged slightly black.

In treatment 5, there was rapid precipitation of humus and the residue assumed a colour much closer to the Black cotton soil.

The mineral clay when treated in the same way as above gave similar results.

It is seen from the above treatments that the hydrogen mineral soil causes a rapid precipitation of humus from neutral solutions.

It is important to note from the above experiments that the presence of calcium either as exchangeable calcium or as calcium carbonate gives a product similar to that of the original black soil.

To see further whether the humus precipitated in the above trials was as free humic acid or as humate or in the form of clay-humus-complex, experiments were conducted to differentiate these various forms of humus. It was found that a 5 per cent solution of ammonium hydroxide preceded by N/5 HCl could dissolve free humus and humate humus, leaving the humus combined with the soil undisturbed as is given in Table IX.

TABLE IX

Differentiation of different forms of humus

Serial number	Organic matter present in the sample	Treatment	Residual organic matter after treatment per cent
1	0·773 per cent as orginally present in the soil	*nil*	0·773
2	Do. Do.	5 gm. of the soil repeatedly shaken up with 100 c.c. portions of 5 per cent ammonium hydroxide	0·785
3	Do. Do.	5 gm. of the soil first treated with N/5 HCL and then treated as in case 2	0·682
4	0·773 per cent as originally present in soil and 4 per cent added as humic acid	Sample treated as in case 2	0·853
5	0·773 per cent as originally present in soil and 4 per cent added as humic acid and 2 per cent added as calcium humate	Sample treated as in case 3	0·920

Although this procedure cannot be recommended as a tentative method unless it is put to an extensive and rigorous test, it was found to be suitable to differentiate the amounts of free and humate humus and the humus combined with the soil mineral matter as a complex.

Table X gives the results of analysis of samples obtained from previous treatments.

TABLE X

Analysis of samples obtained from previous treatments

Serial number	Sample	Mineral matter from black cotton soil		Mineral matter from Mariar soil	
		Per cent organic matter as humic acid and humates	Per cent organic matter as clay-humus-complex	Per cent organic matter as humic acid and humates	Per cent organic matter fixed as clay-humus-complex
1	Slightly alkaline sodium humate and hydrogen soil	0·911	0·309	4·51	0·714
2	Neutral ammonium humate and hydrogen soil	1·631	0·136	4·37	0·714
3	Neutral ammonium humate and calcium soil	1·140	0·231	1·32	0·637
4	Neutral ammonium humate and magnesium soil	1·256	0·341	1·02	0·668
5	Neutral ammonium humate and hydrogen soil with calcium carbonate	1·310	0·293	3·95	1·06

(In case of Mariar soil fixation experiments, the duration of time of fixation of humic matter was double than in the case of black cotton soil.)

It will be seen from columns 3 and 5 of the Table X that the amount of organic matter fixed with the mineral matter of the soil is more or less the same in all treatments and is irrespective of the nature of the treatment. It was also found that the residual matter after the extraction of free and humate humus showed the same black tinge of colour. It, thus, appears that the formation of black colour does not depend on the conditions under which it is formed, but seems to be an intrinsic property of the colloidal clay.

The presence of calcium and other ions in a mineral soil was studied and it was observed that whereas calcium caused a slight but distinctive deepening of colour of the mineral clay or the soil, the other bases like magnesium, sodium, etc., do not show any appreciable effect. It will thus be very clear from above that as far as the black colour formation is concerned, the presence of exchangeable bases is very secondary.

It is known that the silt is next in importance to clay in giving the soil its characteristic properties and in modifying the properties due to clay. It has more recently been shown that silt in some cases is also capable of contributing to the base exchange capacity of the soils. Although it has already been shown that silt does not possess black colour, it was thought that under suitable conditions, it may take black colour by combining with the organic matter. A sample of silt from a black cotton soil was treated with a solution of acidulated permanganate to remove the organic matter and the ash coloured mineral silt thus obtained was then leached with N calcium chloride solution, and then treated with a neutral solution of ammonium humate and kept for several days. It was observed that the sample did not at all take up any black colour, though a little amount of humus got precipitated and coloured the material slightly brown. This clearly shows that the silt is not capable of developing black colour even under the most suitable conditions.

Lastly, to ascertain whether it is the mineral clay from black soils alone that can develop black colour or whether the clays from soils of other colours also possess this property, the mineral matter of the soils and their clays, one red and one yellow, were given similar treatment as silt. It was observed that neither the soils nor their clays developed any characteristic colour of the black soils.

It, therefore, appears that neither the silt of black soils nor the red and yellow soils or their clays are capable of developing black colour. This clearly indicates that it is the intrinsic property of the typical minerals from the clays of black soils that have the capacity to develop the black colour by combination with humus. It has lately been observed by Nagelschmidt, Desai and Muir [1940], and Hosking [1941] that the mineral clays of black soils contain minerals like the montmorillonite and the beidellite that are responsible for the base exchange properties in the clays of black soils. It, therefore, appears probable that it is these minerals that may be combining with the humus to form the black colouring component, namely the clay-humus-complex, rendering thesoils black.

Summary

The role of various mechanical fractions and the organic matter in the formation of colour in typical soils of the State has been studied. The following observations have been recorded in this investigation :

The black soils contain a much higher percentage of clay than the soils of other colours.

The colours of soils can be accounted for on the basis of the colours of their mechanical fractions. The final colour assumed by the soil is dependent on the colours of its mechanical fractions. In case of black soils, clay alone is black, whereas the other fractions are either ashy or ashy-brown in colour. In the case of the red soils all the mechanical fractions contribute to the colour of the soils.

The amount of organic matter (roughly one per cent) cannot account for the black colour in the soils. The organic matter of the black soils is very resistant to the action of reagents. It is only acidulated permanganate that can properly decolourize these black soils and turn them brownish red or brownish yellow. Clays of these soils show similar changes by the action of the reagents. The clays of black soils have a narrower C/N ratio than the clays of soils of other colours.

The black colour of soils can be synthesised by making the basic mineral matter of the clays of black soils or the soils themselves, combine with soluble organic matter. These synthetic experiments show that the black colour formation is an intrinsic property of the mineral clay which fixes the humus in a certain proportion to form the clay-humus-complex which colours the soils black.

It is observed that the mineral matter of the silt of black soils is not capable of developing the black colour under the same conditions mentioned above as does the mineral clay of these soils.

The mineral matter of the red or the yellow soils or their clays is not capable of developing black colour under similar conditions.

The colour of black soils under observations is due to the clay-humus-complex. As is indicated from some of the above observations this complex formation is probably due to certain specific mineral materials present in the clays of black soils.

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STRUCTURE OF THE PUNJAB SOILS

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(With seven text-figures)

SOIL structure is usually defined as the arrangement of soil particles. The capacity of a soil to break up into aggregates of various sizes and shapes is called the structure capacity. It is a matter of common observation that the soils under the influence of the different types of crop rotations, methods of cultivation and climatic changes are undergoing specific structural changes. The natural structural aggregates of the soils, where the surface remains uncovered for a pretty long time break down gradually.

The aggregate analysis of a large number of different soils have yielded significant correlation between climate and aggregation [Baver, 1934]. In addition to the climatic factors, the phenomenon of wetting and drying [Haines, 1923] and freezing and thawing also contribute to secondary particle formation. The real mechanism of aggregate formation is a very complicated phenomenon. The size of the particle, the clay content, the colloidal matter and the vegetation play a dominant role in its formation. Myers [1937] has found that colloidal organic matter is more effective than clay in causing the formation of stable aggregates with sand. Zakharv [1927] and later Gedroiz [1927] have fully dealt with the subject of the genesis of soil structure. The extent of aggregation in different soils varies considerably.

Very little importance has so far been given to this subject in India. From the soil surveys carried out in the Punjab, it has been observed that at different stages of salination or deterioration of the land in the Punjab, colonisation with different types of natural flora takes place. It seems therefore, desirable to investigate how far the different types of vegetation and the inter-relationship of the various soil characteristics could be correlated with the structure of the soil. The second problem which has assumed a great importance in the Punjab is of reclamation of saline soils. Rice with a rotation of some leguminous crop is being used as the method of reclaiming the saline soils [Asghar and Dhawan, 1947]. It was considered of interest to study the effect of this type of crop rotation on the structure of the saline soils.

Collection of soil samples

(*a*) For the present investigation soil-samples were collected from the areas having the following vegetations.

Serial number	Name of vegetation (Local)	Name of vegetation (Botanical)
1	*Kari* . . .	*Cappaaris aphylla*
2	*Jand* . .	*Prosopis spicigera*
3	*Okan* . .	*Tamarix articulata*
4	*Wan* . . .	*Salvadera oleoides*
5	*Lani* . . .	*Sueada fruticosa*
6	Area devoid of any vegetation	

(*b*) For determining the effect of reclamation on the structure of the soil, soil-samples were taken from fields just put under reclamation. The place from where a sample was taken was marked by noting the perpendicular distances from the two adjoining boundaries of the field. Samples representing each foot were collected up to two feet depth from one acre area. After reclamation the sampling was repeated taking great care that the spot selected was as near as possible from where the previous samples were collected.

Experimental

The measurement of structural stability and permeability was carried out by the method proposed by Alderfer and Merkle [1941]. Stability index may be expressed as the sum of the positive difference between the aggregate analysis (by dispersion with water only) and the complete mechanical analysis.

Probable permeability is the percentage of the particles greater than 0·2 mm. in a size distribution curve in a soil when dispersed with water only.

The degree of alkalization is defined as the ratio of the amount of exchangeable monovalent ions (Na+K) in the soil to maximum amount of monovalent ions the soil is capable of binding. The degree of alkalization is equal to Exchangeable

$$\frac{(\text{Na}+\text{K}) \text{ in m.e.} \times 100}{\text{Exchangeable } (\text{Na}+\text{K}+\text{Ca}+\text{Mg}) \text{ in m.e.}}$$

The values of degree of alkalization, dispersion coefficient and *p*H were taken from the paper [Hoon and Metha, 1935]. Dispersion coefficient measures the percentage of total clay that can pass into suspension stage by simple contact with water.

Diagrammatic representation of analytical results

To facilitate the comparison between the various soil characteristics the result of analysis has been represented graphically in Figs. 1-7.

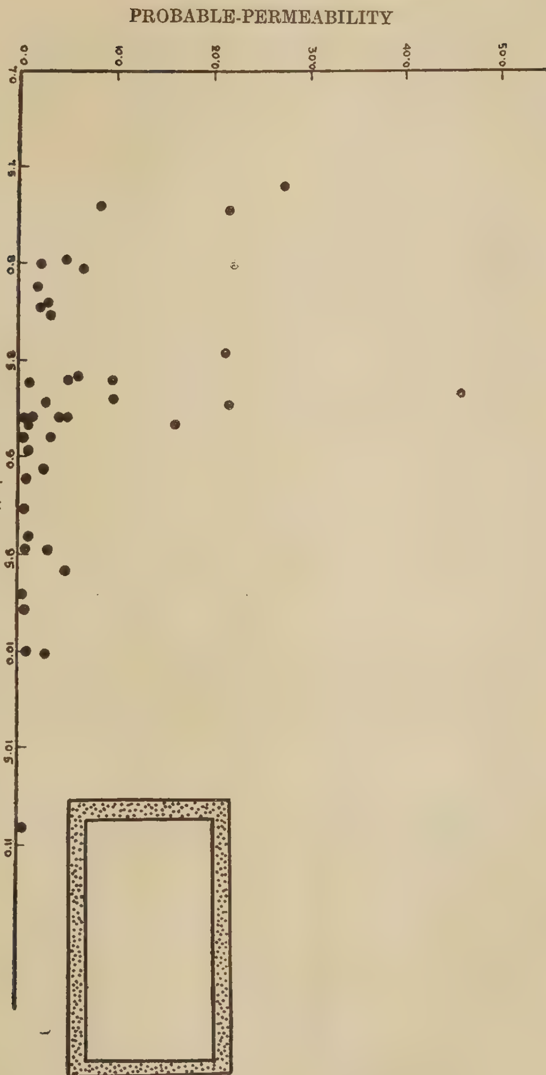

Fig. 1. Showing the relation between probable-permeability and pH.

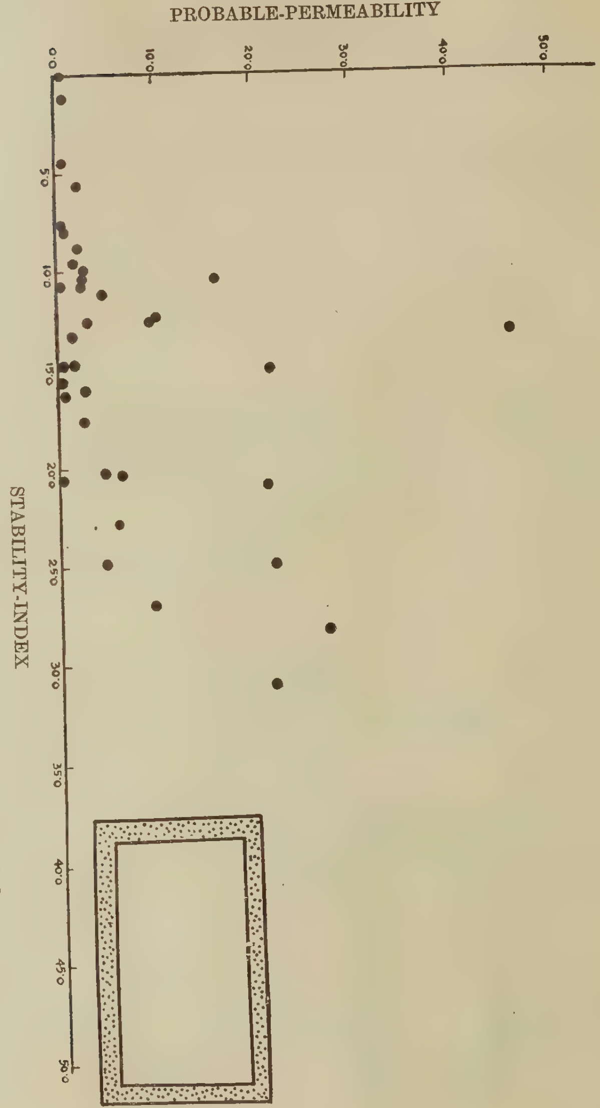

FIG. 2. Showing the relation between probable-permeability and stability-index.

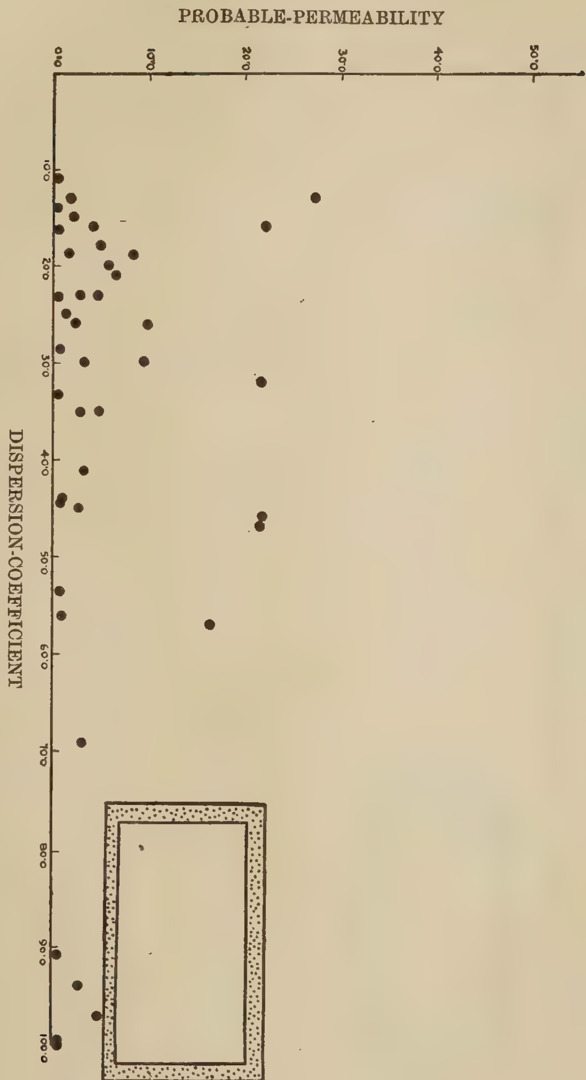

Fig. 3. Showing the relation between probable-permeability and dispersion-coeffi cient.

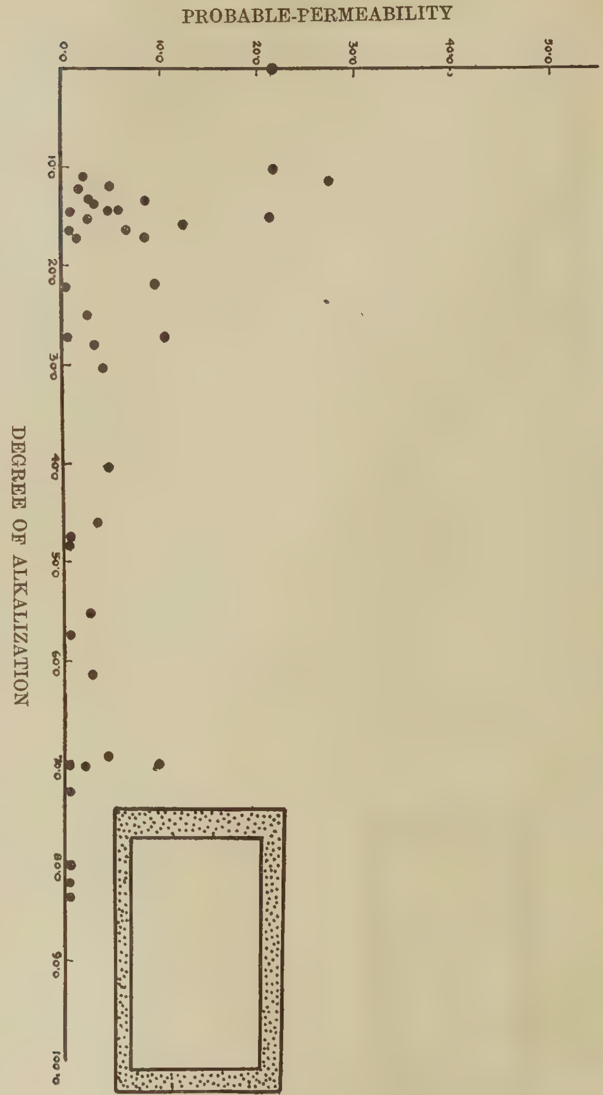

FIG. 4. Showing the relation between probable-permeability and degree of alkalization.

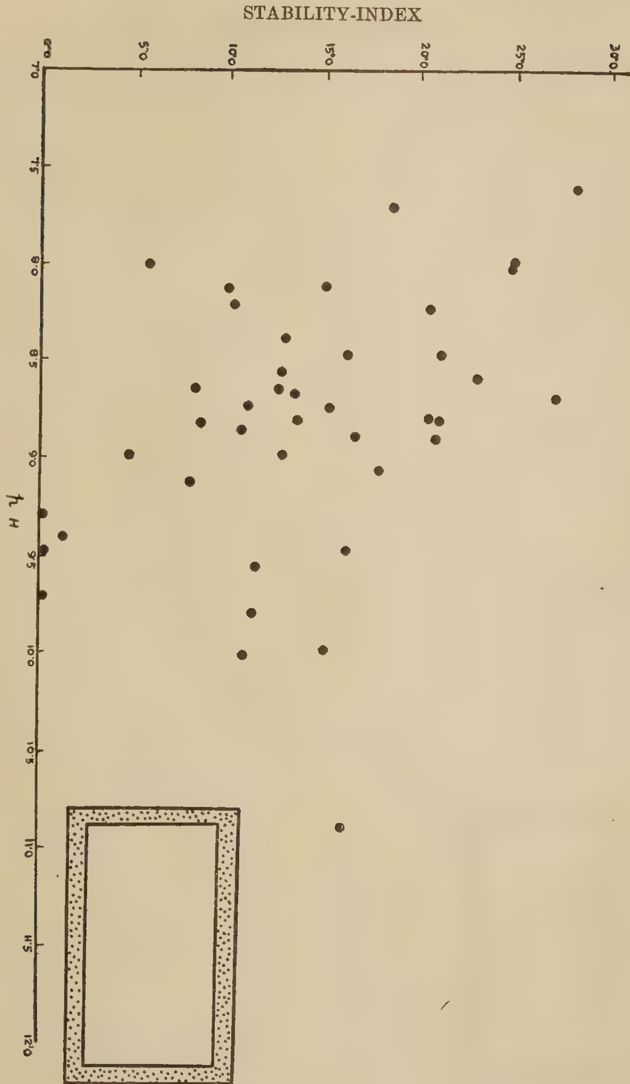

FIG. 5. Showing the relation between stability-index and pH.

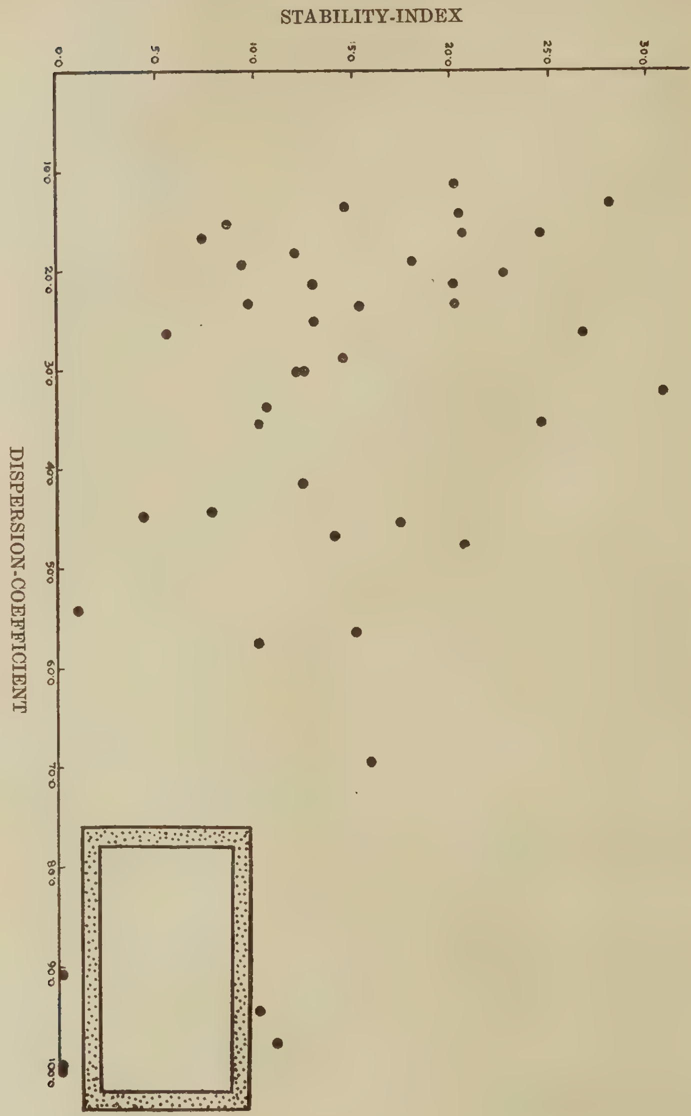

Fig. 6. Showing the relation between stability-index and dispersion-coefficient

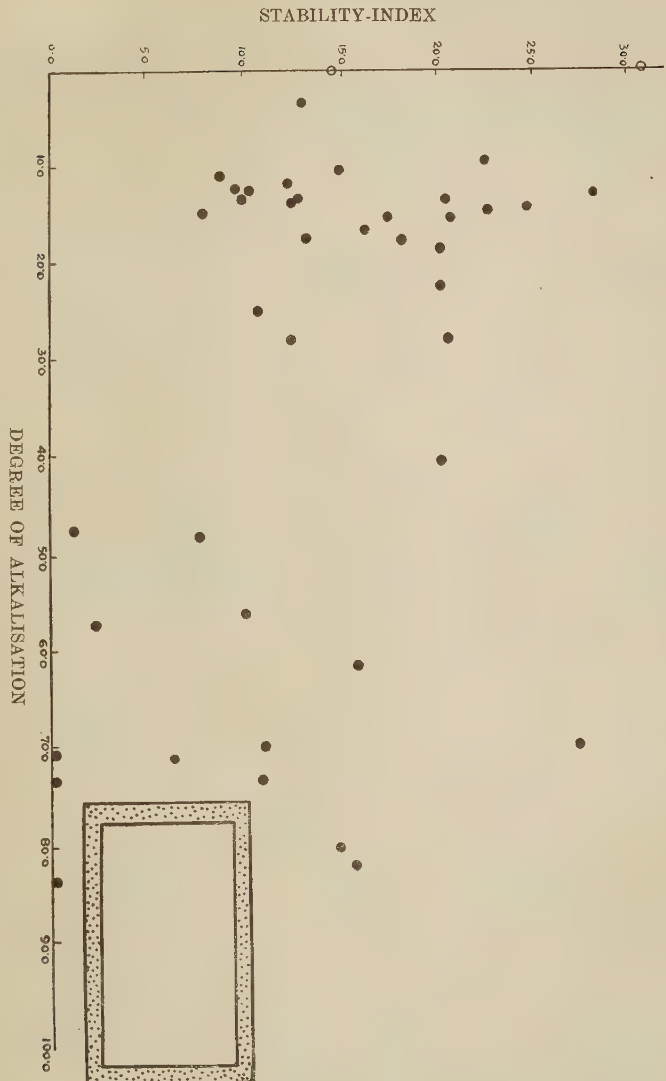

FIG. 7. Showing the relation between stability-index and Degree of alkalization

Statistical treatment of analytical results

An examination of the Figs. 1-7 brings out diagrammatically the sort of relationship between the stability index, probable permeability, *p*H, degree of alkalization and dispersion coefficient and are given in Tables I and II. The following are the notations used in the statistical interpretation of analytical results.

Variable 1=Stability index and probable permeability

Variable 2=Analytical results for the characteristic under consideration *i.e.* degree of alkalization dispersion coefficient and *p*H.

Y 1·2 =Total correlation between variables 1 and 2.

TABLE I

Correlations between stability-index and certain soil characteristics

Serial number	Soil characteristics	Number of observations	r 1·2	Remarks
1	Degree of alkalization	42	—0·3437	Significant
2	Dispersion coefficient	42	—0·5057	Significant
3	*p*H	42	—0·4297	Significant
4	Probable-permeability	42	0·4245	Significant

TABLE II

Correlations between probable permeability and certain soil characteristics

Serial number	Soil characteristics	Number of observations	r 1·2	Remarks
1	Degree of alkalization	42	—0·4043	Significant
2	Dispersion coefficient	42	—0·1854	Insignificant
3	*p*H	42	—0·3906	Significant
4	Stability index	42	0·4245	Significant

Correlation of stability-index and degree of alkalization

The correlation with degree of alkalization is —0·3437 and significant. It shows that the high stability index is associated with low degree of alkalization.

The degree of alkalization is governed by the ratio of sodium and potassium to total bases in a soil. The deterioration of alkali soil is proportional to the extent to which sodium has replaced divalent bases in the soil i.e. how far alkalization has proceeded. Low degree of alkalization means higher percentage of exchangeable calcium, which promotes granulation by a phenomenon called flocculation. This tends to produce crumb structure, which will automatically increase the stability index of a soil.

Correlation of stability index and dispersion coefficient

The correlation with the dispersion coefficient is —0·5057 and significant, showing that high stability index is linked with low dispersion coefficient. The regression equation is $Y+1{\cdot}7X=62{\cdot}3$
where X=stability index
and Y=dispersion coefficient

Correlation of stability index and p*H*

The correlation with *p*H is — 0·4297 and significant It signifies that high stability index is connected with low *p*H values.

It has already been pointed out, that the correlation coefficient of the stability index with degree of alkalization and dispersion coefficient are also negative. All the three soil factors are in fact correlated with one another. The higher the degree of alkalization, the higher are the dispersion coefficient and *p*H values of soils.

the regression equation is

$$Y = -0{\cdot}04\,X+9{\cdot}35$$

where X = stability index
and Y = *p*H

Correlation of stability index and probable permeability

The correlation of stability index with probable permeability is +0·4245 and significant, showing that high stability index is associated with high probable permeability. It is quite natural that with the improvement of the structure of the soil both the characteristics should increase simultaneously. The regression equation is $Y=0{\cdot}5X-1{\cdot}2$
where X=stability index and Y=Probable permeability.

Correlation of probable permeability with degree of alkalization, dispersion coefficient and p*H*

The correlation of probable permeability and degree of alkalization, dispersion coefficient and *p*H are —0·4043, —0·1854 and —0·3906. The insignificant correlation is only with dispersion coefficient.

From the results of correlation, it is evident that the high probable permeability is associated with low degree of alkalization and pH.

The regression equations are

$$Y1 = -1{\cdot}1X1 + 45{\cdot}0$$
$$Y2 = -0{\cdot}03X1 + 9{\cdot}0$$

where X1 = Probable permeability.
Y1 = Dispersion coefficient.
Y2 = pH.

Mutual correlation coefficients between degree of alkalization, dispersion coefficient and pH values of soils

It has been shown that there exist significant correlations between stability index and degree of alkalization, dispersion coefficient and pH. It was considered that the characteristics which gave significant correlation with stability index might have correlation between themselves. Therefore the mutual correlation coefficients of the above characteristics were determined and are given in Table III.

TABLE III

Mutual correlation coefficients

Serial number	Soil characteristics	Number of observations	Correlation coefficient	Remarks.
1	Degree of alkalization with dispersion coefficient	42	+0·5020	Significant
2	Degree of alkalization with pH	42	+0·7127	Significant
3	Dispersion coefficient with pH	42	+0·5174	Significant

All the three correlations are significant and positive. The results indicate that a high degree of alkalization is associated with a high dispersion coefficient and pH. The same relation holds good in the case of dispersion coefficient and pH, which means that the relations between the characteristics are directly proportional.

Partial correlation coefficient

It has already been stated that the correlation of stability index with pH and dispersion coefficient are negative, and significant and the correlation of probable permeability with pH and degree of alkalization are negative and significant. On further analysis it has been found that there exists significant correlation between degree of alkalization and dispersion coefficient and pH and between dispersion coefficient and pH. It was therefore, thought necessary to determine the partial coefficient between the characteristics as it would give us an idea of the association

between the two characteristics when the effect of the third was eliminated.

TABLE IV

Partial correlation coeffic'ents

Serial number	Soil characteristics	Correlation coefficient	Value of t	Remarks
1	Stability Index with dispersion coefficient when the effect of other constants is deleted out	—0·3904	—2·61	Significant
2	Stability index with *p*H when the effect of other constants is eliminated	—0·1344	—0·84	Insignificant
3	Stability index with degree of alkalization when the effect of other constants is eliminated	—0·0972	—0·61	Insignificant
4	Stability index with probable-permeability	0·3537	2·37	Significant
5	Probable permeability with degree of alkalization	—0·2249	—1·44	Insignificant
6	Probable permeability with dispersion-coefficient	—0·1683	—1·06	Insignifican
7	Probable permeability with *p*H	—0·0974	—0·61	Insignificant

Table IV gives the partial correlation coefficient between the various characteristics. In order to determine the significance of the correlation coefficient, the value of t was calculated by the formula.

$$t=\frac{r\ 12\cdot345\sqrt{n-3}}{\sqrt{1-(r12\cdot345)^2}}$$

The only significant correlation is with the dispersion coefficient. It is, therefore, concluded that the structure of the soil is mainly governed by the dispersion coefficient.

Effect of reclamation on the structure of the soil

The average values of probable permeability and stability index in the first and second foot before and after reclamation are given in Table V. There is an increase in probable permeability and stability index after reclamation. The increase in stability index is over 50 per cent.

TABLE V

Effect of reclamation on the structure of the soil

Serial number	Probable permeability		1·0-2·0 ft. before reclamation	After reclamation	Stability index		1·0-2·0 ft. before reclamation	After reclamation
	0-1·0 ft. before reclamation	After reclamation			0-1·0 ft. before reclamation	After reclamation		
1	6·4	21·2	4·0	8·4	4·0	10·4	4·2	12·2
2	16·4	26·4	14·0	22·4	0·8	4·0	0·0	5·6
3	14·8	19·6	22·0	10·4	0·0	4·0	1·2	2·2
4	14·8	25·6	5·6	10·2	10·2	14·4	2·2	8·2
5	16·4	5·2	10·8	12·4	15·2	20·0	1·8	13·6
6	20·0	28·0	22·6	20·0	0·0	2·4	3·6	0·0
7	13·6	11·6	11·2	8·8	0·0	2·4	0·0	1·2
8	3·5	18·8	19·0	25·4	6·1	1·6	0·0	4·1
9	6·8	14·0	6·4	6·8	14·0	23·8	7·8	18·8
10	11·0	20·0	7·2	18·0	12·8	23·2	26·4	16·0
11	21·2	14·0	20·8	14·0	9·2	14·8	19·6	26·4
12	3·2	7·2	1·6	2·4	0·8	2·4	3·2	2·0
13	3·2	2·0	1·1	2·4	0·0	1·6	2·0	4·0
14	9·2	18·4	18·0	4·8	8·6	22·0	2·4	2·4
15	4·5	3·2	2·8	13·6	3·6	0·0	1·2	11·8
16	4·8	4·8	3·1	12·0	4·9	3·6	5.0	1·4
17	3·6	8·0	5·6	8·0	0·0	0·8	0·0	2·2
18	3·2	2·0	2·8	4·0	0·0	2·8	0·0	5·2
Average value 10·4	10·4	13·9	9·9	11·3	5·6	7·6	4·5	7·6

During the process of leaching under the rice cultivation carbon-dioxide is produced in the roots of the plants. The *p*H values of the solution of carbon dioxide is about four. The carbon dioxide released at the roots of the plants, therefore, plays the following role [Puri and Puri ; Puri and Uppal, 1938].

1. It lowers the *p*H values
2. It flocculates the dispersed soil and increases the rate of percolation.
3. It brings more of the exchangeable sodium of the soil into solution.

It has also been observed that there is an increase in the exchangeable calcium content of soils after reclamation.

The principal salt present in the saline soils of the Punjab is sodium sulphate. The reaction between sodium sulphate and calcium contained in the soil results in the formation of calcium sulphate (Irrigation Research Institute, 1945) which ameliorates the structure of the soil. The gram crop further improves the structure

TABLE VI

Showing the probable permeability and stability index of the soil profiles taken from areas having different types of natural vegetation

Serial number	Depth	pH	Dispersion coefficient	Degree of alkalization	Probable permeability	Stability index
(A) *Kari*						
			Profile I			
1	0-9 cm.	8·62	44·0	14·71	0·8	8·0
2	9-16 cm.	8·84	56·0	16·50	0·8	16·4
3	16-122 cm.	10·01	94·0	55·06	2·4	10·4
			Profile II			
1	0-5 cm.	8·58	30·0	13·59	9·2	12·8
2	5-26 cm.	8·02	16·0	9·31	22·0	24·8
3	26-60 cm.	7·96	26·0	60·85	2·0	5·6
4	60-77 cm.	8·12	19·0	12·10	1·6	9·6
5	77-97 cm.	8·12	13·0	0·0	1·6	14·8
6	97-122 cm.	8·22	15·0	11·0	2·0	8·8
(B) *Jand*			Profile I			
1	0-18 cm.	8·49	28·0	12·82	..	..
2	18-34 cm.	8·20	23·0	13·31	2·6	10·0
3	34-78 cm.	8·91	14·0	27·30	0·20	20·6
4	78-101 cm.	8·81	16·0	30·22	4·00	20·8
5	101-122 cm.	8·81	11·0	22·23	0·20	20·4
			Profile II			
1	0-7 cm.	7·69	19·0	17·02	8·2	8·4
2	7-19 cm.	8·24	21·0	16·46	6·3	20·4
3	19-41 cm.	8·65	18·0	11·96	4·9	12·4
4	41-80 cm.	9·47	69·0	61·17	2·8	16·0
5	80-182 cm.	9·57	97·0	69·7	4·4	11·2

TABLE VI—*contd.*

Showing the probable permeability and stability index of the soil profiles taken from areas having different types of natural vegetation

Serial number	Depth	*p*H	Dispersion coefficient	Degree of alkalization	Probable permeability	Stability index
			Profile III			
1	0-2 cm.	7·59	13·0	11·43	27·2	28·2
2	2-6 cm.	7·73	32·0	0·0	21·7	30·8
3	6-19 cm.	7·97	33·0	14·39	4·5	24·8
4	19-33 cm.	8·55	30·0	27·96	3·0	12·6
5	33-58 cm.	8·81	23·0	40·45	4·5	20·4
6	58-95 cm.	8·70	26·0	70·15	9·6	26·8
(C) *Okan*						
1	0-15 cm.	8·72	35·0	24·98	2·4	10·7
2	15-53 cm.	8·58	20·0	14·53	5·6	22·8
3	53-81 cm.	8·81	25·0	17·35	1·2	13·4
4	81-108 cm.	8·91	41·0	13·72	3·0	12·6
5	108-122 cm.	9·07	45·0	15·28	2·4	17·6
(D) *Wan*						
1	0-4 cm.	8·46	47·0	15·05	21·2	20·8
2	4-36 cm.	8·84	57·0	12·29	16·0	10·4
3	36-75 cm.	8·74	46·0	10·09	21·6	15·0
4	75-122 cm.	8·67	21·0	3·04	46·0	13·2
(E) *Lani*						
1	0-6·5 cm.	6·97	44·2	57·4	0·7	4·5
2	6·5-28·0 cm.	9·48	90·8	70·5	0·4	0·0
3	28·0-55·5 cm.	9·41	53·7	47·8	0·7	1·10
4	55·5-84·0 cm.	9·1	16·4	48·2	0·4	7·6
(F) Area devoid of vegetation						
1	0-13 cm.	9·28	100·0	73·44	0·34	0·0
2	13-17·8 cm.	9·70	99·73	83·94	0·14	0·0
3	17·8-45·7 cm.	9·79	33·10	73·20	0·40	10·8
4	45·7-81·3 cm.	10·90	23·18	82·40	0·30	15·6
5	81·3-122 cm.	10·00	28·70	80·12	0·60	14·8

Native vegetation as an index of soil structure

Table VI shows the probable permeability and stability-index of the soil profiles relating to different types of natural vegetation. The examination of analytical results by the method of correlation analysis have revealed that negative correlations are obtained between the stability index and probable permeability with *p*H, dispersion coefficient and degree of alkalization. The stability index and probable permeability are also positively correlated with each other. From the very low values of probable permeability and stability index it is concluded that *lani* and areas devoid of vegetation are of the advanced stages of land deterioration. The stability index is the highest in case of *jand*. Soils where *jand* is the principal natural flora growing can be brought under natural cultivation and may therefore, be assumed as good. The values of probable permeability are very low in *kari* profiles. The *p*H of the horizons (16-122) centimeters are very high. The presence of *kari*, therefore, represents a soil on which crop production is likely to be limited by the alkalinity of the soil. The results of stability index and *other* soil characteristics show that soils under *okan* and *wan* cannot be classed as good as those carrying *jand*. Therefore, the natural flora is sufficiently a good indicator of the type of the soil.

Summary

Native vegetation is a useful index for the structure of the soil.

The structure of the soil is mainly governed by the dispersion coefficient.

Reclamation improves the structure of the saline soil.

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THE OCCURRENCE AND SIGNIFICANCE OF TRACE ELEMENTS IN RELATION TO SOIL DETERIORATION

II. BORON

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THE growing volume of work on the trace elements in soils is indicative of the importance attached to the subject by the Agricultural Scientists. Boron also occupies a conspicuous position amongst this class of elements. That is essential for the normal growth of plants, has been known since the investigations of Worrington [1923].

Boron deficiency symptcms have been revealed by plant and soil tests [Berger and Truog, 1940]. Askew, Thomson and Kidson [1937] found in New Zealand soils, quantities of boric acid (acid soluble), ranging from 0·15 to 2·2 p.p.m. Terlikowski and Nowicki [1932] found that the boron content of Polish soils ranged between 1 to 14 p.p.m. The Russian soils as investigated by Bobko [1937] were found to contain very small quantities of boron varying from 0·11 p.p.m. in red soils to 0·27 p.p.m. in chernozems (water-soluble).

Drake [1941] determined calcium boron ratio and found that if the ratio was lower than two hundred, the plants exhibited boron deficiency. At a ratio approximately 600, the plants were healthy. Schuster [1940] found that sun-flower could be used as an index of boron deficiency in soils.

Very little attention has been paid to this problem in India. Hoon and Dhawan [1943] had been working on the role of manganese in Punjab soils. Ghani [1945] studied the boron status of a few Bengal soils (water soluble). He found out that the range of boron was from 0·4 p.p.m. to 2·0 p.p.m. and there was no apparent relation between the availability of boron and the organic matter and exchangeable calcium content of the soils. He further stated that the boron content of the soils increased on ignition. It was thought desirable to study the boron status of the Punjab soils with special reference to soil fertility and deterioration.

Experimental

The method proposed by Smith [1935] was adopted for the determination of boron in soils. Boron was extracted from the soils by boiling the soil with water in a flask fitted with reflux condenser, for varying periods of time. The method was standardized by adding known quantities of boron in two different types of soils and extracting the boron by the above procedure. It was noticed that half an hour boiling was sufficient for the extraction of water-soluble boron. The extract was filtered and boron determined in an aliquot portion colorimetrically with quinalizarin.

The pH of 1 : 5 soil suspension in water was determined by glass electrode.

The exchangeable calcium was determined by Puri's method [1936].

Discussion

Soil profiles from areas with low water table

The Punjab soils being alluvium, are of recent formation, and they do not exhibit any well developed soil profiles, as are found in the hilly regions. Therefore, the soil samples were taken at known depths along the profile up to the water table from a number of places and examined for boron content. The results of a few soil profiles, are given in Table I.

Table I

Results of the boron content of soil-profiles taken from different places

Soil profile number 1			Soil profile number 2			Soil profile number 3		
Serial number	Depth in ft.	Boron p.p.m.	Serial number	Depth in ft.	Boron in p.p.m.	Serial number	Depth in ft.	Boron in p.p.m.
1	0-1 ft.	4·0	1	0-1 ft.	2·5	1	0-1 ft.	5·0
2	1-2 ft.	3·0	2	1-2 ft.	2·0	2	1-2 ft.	3·0
3	2-3 ft.	5·0	3	2-3 ft.	4·0	3	2-3 ft.	6·0
4	3-4 ft.	5·0	4	3-4 ft.	5·0	4	3-4 ft.	2·5
5	4-5 ft.	6·0	5	4-5 ft.	6·0	5	4-5 ft.	4·3
6	5-6 ft.	3·0	6	5-6 ft.	2·0	6	5-6 ft.	3·5
7	6-7 ft.	2·5	7	6-7 ft.	4·5	7	6-7 ft.	3·0
8	7-8 ft.	2·0	8	7-8 ft.	5·0	8	7-8 ft.	4·0
9	8-9 ft.	3·0	9	8-9 ft.	2·0	9	8-9 ft.	2·5
10	9-10 ft.	3·5	10	9-10 ft.	1·5	10	9-10 ft.	2·0
11	10-11 ft.	2·0	11	10-11 ft.	2·0	11	10-11 ft.	2·0
12	11-12 ft.	1·5	12	11-12 ft.	1·5	12	11-12 ft.	1·5
13	12-13 ft.	1·5						
14	13-14 ft.	1·5						

It is brought out that boron is present throughout the depth of the profile. The range of boron content varies from 1·5 p.p.m. to 6·0 p.p.m. Ghani [1945] found that the range of boron in Bengal soils varies from 0·4 p.p.m. to 2·0 p.p.m. The greatest quantity was found in Polish soils ranging from 1·0 to 14 p.p.m. by Tertikowiski and Nowicki [1932].

Boron even in such amounts manifested a negative correlation with the yield of wheat in the Punjab soils [Hoon, Dhawan and Madan, 1941], and the boron content of soils did not seem to indicate any relation to the yield of rice [Hoon, Dhawan and Madan, 1946].

Boron content of soils in relation to productivity

From the data of the yield of major agricultural crops, a few sites were classed as good, average and poor. Soil samples were taken from these sites and the boron content determined. The results of analyses of these samples are presented in Table II.

TABLE II

Results of analyses of soil-samples with reference to the cropping condition at the site

Serial number	Description of site, etc.	Depth of soil sample	pH	Boron content in p.p.m.	Exchangeable calcium in M. E. per 100 gm. of soil	Calcium / Boron	Classification of land on the basis of productivity
1	Wheat field from Moghalpura	0-1 ft.	7·5	3·0	12·5	833·3	Good
2		1-2 ft.	8·2	5·0	13·2	528·0	
3		2-3 ft.	7·8	4·0	11·8	590·0	
4		3-4 ft.	8 2	3·5	12·6	720·0	
					Average	667·8	
1	Cotton field from Montgomery	0-1 ft.	8·1	4·0	11·2	560·0	Good
2		1-2 ft.	8·3	4·5	10·8	480·0	
3		2-3 ft.	7·6	3·5	12·0	685·7	
4		3-4 ft.	8·6	5·9	10·8	412·0	
					Average	535·1	

TABLE II—*contd.*

Results of analysis of soil-samples with reference to the cropping condition at the site

Serial number	Description of site.	Depth of soil sample.	pH.	Boron content in p. p. m.	Exchange-able calcium in M. E. per 100 gm. of soil.	Calcium / Boron	Classification of land on the basis of productivity
1	Mahran wala (Jaranwala)	0-1 ft.	8·6	6·0	8·0	266·6	Average
2		1-2 ft.	8·85	4·5	6·5	288·8	
3		2-3 ft.	8·5	5·5	5·5	210·9	
4		3-4 ft.	8·7	3·0	5·2	346·6	
					Average	278·2	
1	Sheikhupura	0-1 ft.	9·5	6·5	3·6	110·8	Poor
2		1-2 ft.	9·8	7·0	4·5	128·8	
3		2-3 ft.	10·2	6·0	3·5	116·6	
4		3-4 ft.	9·4	5·5	2·4	87·2	
					Average	110·8	

It is concluded that there is comparatively a higher boron content in soils representing areas of poor or bad yields of crops than those from areas with average or good yield, and the ratio of the calcium/boron is also higher in good soils, than in bad ones. The average value of calcium /boron ratio (Table II) is more than 500 for good soils and 110 or lower for poor ones. Drake [1941] had also shown that the ratio of calcium/boron could be used as an index of fertility and deterioration. But his experiments showed that the plants were healthy at a ratio of about 600 and the deterioration set in below 200.

During the course of soil surveys, it was noticed that the different types of natural flora were growing on different types of soils and the flora could well indicate the type of a soil [Hoon and Mehta 1937] and [Hoon and Dhawan, 1948].

Soil-samples were brought from the profiles bearing different types of natural vegetation and analyzed for boron content and other soil constants. The results of analyses are given in Table III.

TABLE III

Results of analyses of soil-samples from areas bearing natural vegetation

Serial number	Type	Depth in inches	pH.	Boron content in p.p.m.	Exchange-able calcium in M. E. for 100 gm. of soil	Calcium / Boron	Remarks
1	Profile taken from an area under *lani* (*Sudae-fruticosa*)	0-2·5 in.	8·97	8·0	4·2	103·0	Deteriorated
		2·5-11 in.	9·48	7·0	1·3	24·3	
		11-22 in.	9·41	5·0	2·5	100·3	
		22-33 in.	9·11	8·0	6·6	165·0	
		33-48 in.	9·24	8·0	2·7	67·5	
					Average	94·3	
2	do.	0-4 in.	9·76	5·0	0·0	0·0	Deteriorated
		4-15 in.	10·15	6·0	1·35	45·0	
		15-24 in.	9·87	5·0	0·85	28·3	
		24-36 in.	9·64	7·0	2·5	71·4	
					Average	36·2	
3	Devoid of any vegetation	0-½ in.	9·28	8·0	1·92	48·0	Last stage in deterioration
		½-7·1 in.	—	—	—	—	—
		7·1-17·9 in.	9·99	10·0	2·52	50·4	
		17·9-32 in.	10·9	10·0	0·9	18·0	
		32·0-48 in.	10·0	10·0	1·1	22·0	
					Average	34·6	
4	Karai (*Capparisaphylla*)	0-2 in.	8·58	0·0	5·19	0·0	*Average*
		2-10·1 in.	8·02	2·5	6·96	556·8	
		10·1-24 in.	7·96	2·0	4·39	439·8	
		24-30·8 in.	8·12	4·0	2·85	142·5	
		30·8-38·8 in.	8·12	4·0	4·31	215·5	
		38·8-48 in.	8·22	3·0	2·35	156·6	
					Average	302·1	
5	Wan (*Salvadora oleoides*)	0-1·5 in.	8·46	1·0	9·13	1826	*Good*
		1·5-4 in.	8·84	0·5	9·27	3708	
		4-14 in.	8·74	2·0	9·31	931	
		14-48 in.	8·67	1·0	9·58	1916	
					Average	2095·25	

The average value of calcium/boron ratio of the *lani* (*Suaeda fruticosa*) and bare-patch (*devoid of any vegetation*) profiles is less than hundred, indicating, that the profiles are in an advanced stage of deterioration. From the values of calcium/boron of *karai* (*Capparisaphylla*) and the *wan* (*Salvedora oleoides*) profiles, it is concluded that the soils may be classed as average and good respectively and may be easily put under normal cropping.

Effect of ignition on the boron-content of soils

Ghani [1945] while working on the Bengal soils concluded that the boron content of the soils increased on ignition. A number of Punjab soils were selected and the boron content determined before and after ignition. The results are embodied in Table IV.

TABLE IV

Results of the boron content of soils before and after ignition

Serial number	Boron content in p.p.m. before ignition	Boron content in p.p.m. after ignition
1	8·0	2·0
2	7·0	1·0
3	5·0	2·0
4	8·0	1·5
5	8·0	2·0
6	4·0	1·5
		Trace
7	3·0	2·0
8	5·0	1·0
9	5·0	1·5
10	6·0	1·0
11	3·0	0·5

The values have decreased considerably after ignition. The experiments were repeated after adding known quantities to a soil and the values determined before and after ignition. There was a substantial lowering in the boron content of soils after ignition. The explanation is not far to seek. Most of the boron on ignition forms insoluble complex compounds with aluminium, iron and calcium, and, therefore, the water soluble quantity is decreased.

SUMMARY

Boron is present in soils even at very low depths

Deteriorated soils are associated with relatively greater boron content than good or average soils

The calcium/boron ratio may be used for the classification of soils in relation to fertility and deterioration.

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REVIEWS

THE JOURNAL OF SOIL SCIENCE

EDITED BY G. V. JACKS, M.A.

(*Published by Oxford University, Amer House, London E.C. 4, 1950, pp. 253, price 17 s.*)

THE Journal contains original papers and reviews of considerable interest. To students of Soil Survey and Soil Science the reviews by *e.g.* Stephens on *Comparative morphology and genetic relationship of certain Australian, North American and European Soils* and G. W. Robinson's notes on soil classification will be of great help. Stephens in his review on Australian soils brings out common characteristics of typical Australian soils as podsols, chernozems, rendzina and their analogues in North Africa and Europe and discusses peculiar features of formation of these soils in Australia and their classification. G. W. Robinson discusses general features of different systems of soil classification and their philosophical significance. Regarding classification of soil types, D. V. Crawford's paper is also interesting. The Journal covers a wide range from soil systematics, soil physics and chemistry, studies on phosphate fixation as also studies of clay mineral and their interpretation. On phosphate fixation studies, the up-to date review by Alan Wild will be of immense help to workers on that problem. Soil aggregation and the influence of different constituents of humus and earth-worms have been studied by R. J. Swaby, in two original papers in this Journal. Swaby gives a short but quite exhaustive account of important work on the influence, different forms of organic substances and microbes on soil aggregation. This will be of great help to the workers on the subject. Experiments designed to induce gleying in soils, reported in the Journal by C. Bloomfield, to elucidate the mechanism of gleying process is worth noting. Other important original contributions worth mentioning are on 'equilibrium of rain fed water resting on deeper saline water by E. C. Childs which gives theoretical treatment of the subject and interpretation of X-ray diagram of clay minerals by G. Brown and D.M.C. Macewan which also is a theoretical study of X-ray data to elucidate the nature of clay minerals and their hydration. The Journal is thus full of valuable information and to be recommended to every student and worker in Soil Science. (S.P.R.)

FORAGE CROPS

By Gilbert H. Ahlgren

(*Published by New York, McGraw-Hill Book Co., Inc., 1949, pp. 418, illustrated, \$5-00*)

THE publication of a book on an aspect of agronomy indicates that the subject has advanced to a degree that both its teaching and further research in it requires up to date information brought together in the form of a book. That such is the position with regard to the production of forage crops in the United States of America becomes evident from a perusal of the book under review.

The book deals with the more important legumes, grasses, millets and cereals that are of forage value in the United States of America. Some of the more important forage crops are dealt with individually and others considered in groups. The pride of place is given to alfalfa or lucerne which is the most important forage crop of the States considered both from its nutritive point of view and the extent of its spread. Information furnished in respect of each crop includes when, how and from where the crop was introduced into the States, its climatic and cultural requirements, yield and its response to manurial and other treatments, feeding value and other uses and varietal differences and their suitability for different purposes. Important information furnished is supported by recorded data which are given in over 390 tables.

Among the legumes dealt with the only one which is grown in India on a small scale is alfalfa and an attempt is being made to acclimatize Kudzu in this country. There are some practical instructions given on the culture of these two crops some of which may be worth trying in this country.

It is mentioned that Jhonson grass (*Sorghum halepense*) which was considered as a weed pest in the United States of America is beginning to be recognized as a forage crop of potential value. In India too where it is considered of little importance if attempts could be made towards its development it may turn out to be a source of valuable forage. It is interesting to note that Bermuda grass (*doob* or *hariali—Cynodon dactylon*) which is a pasture grass of importance in the Southern States of the United States of America was first introduced into the States from India and two improved varieties of it have been evolved.

The importance of sorghum, millets and corn for fodder and grain and of cereals for hay is dealt with in a few chapters. Soil improvement by application of major and minor elements and F. Y. M., seed bed preparation which is of prime importance in the production of forage legumes, placement and selection of seed and silage making receive adequate treatment.

Some interesting information is furnished as for instance that in the United States of America, grass farming which was known from early colonial times had

declined to a state of low carrying capacity, productiviy and quality until the First World War when the importance of grass being realised steps were taken to revive and develop the practice. The Dairymen in America have come to know that it is four times as costly to stall feed milch cow as to have it pasture fed. In the same country grass is now considered a crop and receives all the attention and care as a grain or truck crop receives. These changes in outlook have taken place because of the important role forage crops play in the animal husbandry of the States. How very much different is the position in this country needs no comment.

The chapter on grass and legume mixtures points out the benefits of growing these two crops as mixture than to grow them singly. The chapters on identifying of forage plants and their seeds are useful additions to the already adequately treated subject matter of the book. Another important chapter is that on the part played by plant breeding in the improvement of forage crops. It lists several of the improved strains of grasses and clovers which have gained importance in commerce and in which a flourishing seed trade exists. The diseases affecting forage crops is dealt with in a chapter. Related aspects of forage crop production is covered by the author and information is furnished on fixing hay standard, production of quality herbage labour saving, etc.

The book furnishes considerable information of importance to workers even in our country where hardly the beginnings of an attempt to improve forage crops has yet been made. The extent to which modern machinery is used in forage production can be seen from the illustrations alone.

References appropriate to the subject matter are given at the end of each chapter and the large number of illustrations and an index serve as useful additions. Reading the book one is impressed with the strides of advance made in the United States of America and it overwhelms one's mind to think of the considerable lee way that has yet to be made in this country where the pace of progress is slow and attempts made too meagre, to do anything tangible. (L.S.S.K.)

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ERRATA

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Page	*Line*	*For*	*Read*
2	Fig. 1	(Caption missing)	Map showing river system of Bakarganj District. Scale 1 in=16 miles.
8	4	distint	distinct
39	Foot note	Institutes	Institute
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116	3	rabici	rabiei
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139	7	Ham.,	Ham., Chirata

PRIZE

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Messrs. Gardners Corporation, New Delhi, have offered a prize of Rs. 200 per year to the best contributor of an article on 'fruit preservation and canning'. While giving this award they have selected, besides one or two other Journals, the two Journals of the Indian Council of Agricultural Research, *viz.*, Indian Journal of Agricultural Science and Indian Farming, out of which, contributors of articles on the subject have to be selected. The award has been given on an annual basis and the first award will be given to the contributor of the best article on the subject during the period 1-1-51 to 31-12-51. To adjucate articles, a Committee consisting of the following gentlemen has been formed :—

(1) Dr. V. Subrahmanyan, Director, Central Food Technological Research Institute, Mysore.

(2) Dr. Girdhari Lall, Asst. Director (Fruit Technology), Central Food Technological Research Institute, Mysore.

AND

(3) Shri Kailash Nath of Messrs. Harnarain Gopi Nath of Delhi and Hony. Secretary, All India Food Preservers' Association, Delhi.

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The Publications Committee of the Indian Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

Original articles

The Editorial Board, in its work of examining papers received for publication, is assisted in an honorary capacity by a large number of scientists working in various parts of India.

Editorial communications including books and periodicals for review should be addressed to the Secretary, Indian Council of Agricultural Research, Publication Section, New Delhi.

Communications regarding subscription and advertisements should be addressed to the Manager of Publications, Civil Lines, Delhi.

INSTRUCTIONS TO AUTHORS

Articles intended for *The Indian Journal of Agricultural Science* should be accompanied by short popular abstracts of about 330 words each.

In the case of botanical and zoological names the International Rules of Botanical Nomenclature and the International Rules of Zoological Nomenclature should be followed.

Reference to literature, arranged, alphabetically according to author's names, should be placed at the end of the article, the various reference to each author being arranged chronologically. Each reference should contain the name of the author (with initials), the year of publication, title of the article, the abbreviated title of the publication, volume and page. In the text, the reference should be indicated by the author's name, followed by the year of publication enclosed in brackets ; when the author's name occurs in the text, the year of publication only need be given in brackets. If the reference is made to several articles published by one author in a single year these should be numbered in sequence and the number quoted after year both in the text and the collected references.

If a paper has not been seen in original it is safe to state 'original not seen'. Sources of information should be specifically acknowledged.

As the *format* of the journal has been standardized, the size adopted being crown quarto (about 7½ in. × 9⅝ in. cut), no text figure, when printed should exceed 4½ in., 5 in. Figures for plates should be so planned as to fill a crown quarto page, the maximum space available for figures being 5¾ in. × 8 in. exclusive of that for letter press printing.

Copies of detailed instructions can be had from the Secretary, Indian Council of Agricultural Research, New Delhi.